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Spacelab Timing Analysis

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SHUTTLE PROGRAM

SPACELAB TIMING ANALYSIS

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Section 1

Introduction

1.1 PURPOSE

This document presents the results of a study of the Orbiter/Spacelab Timing Systems. The approach used was to describe the generation of the timing signals in the Orbiter and follow this distribution to the Spacelab experiments. The objective of this report is to identify the accuracy to which data may be time tagged in Spacelab. This document also attempts to give some insight into how the data is collected in Spacelab and transmitted to the ground.

This report is based on information gathered from the references listed in Appendix A and is meant to be a report on time tagging of science data in Spacelab. The results contained in this report are for information purposes only and are not intended to be binding standards.

1.2 SCOPE

This study addressed only those portions of the Orbiter/Spacelab Systems which dealt with the generation and distribution of timing signals. Functions of these elements not related to timing were not considered in this report. Such considerations are beyond the scope of this document.

A portion of the information presented must necessarily be considered as preliminary, since many experiments and Spacelab design issues are not yet resolved.

2.0 Orbiter/Spacelab Timing System Overview.

2.1 Orbiter Timing System.

This section discusses the timing related functions of the Master Timing Unit (MTU), the Pulse Code Modulation Master Unit (PCMMU), and the General Purpose Computer (GPC).

2.1.1 Master Timing Unit.

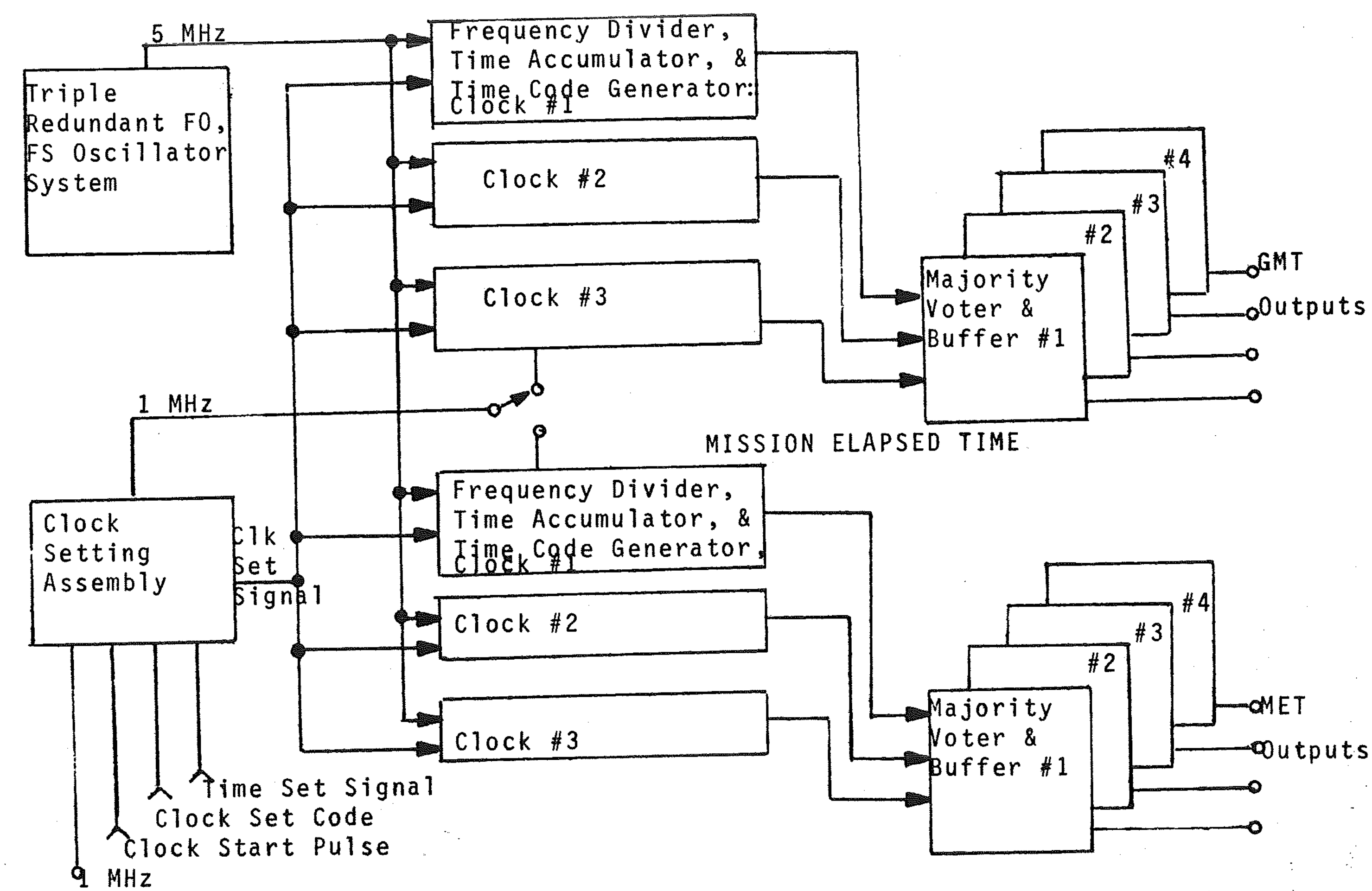
The Master Timing Unit (MTU) is a stable crystal controlled frequency source which provides frequency outputs to selected Shuttle Orbiter subsystems and payloads. A block diagram of the MTU is shown in Figure 2-1. The MTU has separate time accumulators for Greenwich Mean Time (GMT) and Mission Elapsed Time (MET) which can be set or updated by external control. The MTU is initialized prior to lift-off and only updated after that.

2.1.1.1 Interface Definition.

The MTU interfaces with the Orbiter Data System through a Multiplexer/Demultiplexer (MDM) which supplies operational commands via a serial data stream and discrete DC voltage control signals. The MTU provides GMT, MET, and Built-In-Test-Equipment (BITE) status word via the MDM interface to the General Purpose Computers (GPC) and Pulse Code Modulation Master Units (PCM MU). GMT and MET are also generated by the MTU in a modified IRIG-B format for the crew displays.

2.1.1.2 Frequency Stability.

The crystal controlled oscillators used in the MTU are capable of providing the following frequency



MTU BLOCK DIAGRAM
Figure 2-1

stability:

A. The long term stability or drift of the oscillator is less than or equal to one part in 10^9 per day.

B. The short term stability or drift of the oscillator for the RMS of 100 successive frequency measurements of one second in duration is less than one part in 10^{10}.

The frequency of the oscillator is 4.608 MHz or a binary multiple thereof. The MTU can be set to within 0.1 milliseconds of ground time pre-liftoff and to that granularity (but not that accurately) on orbit.

2.1.1.2.1 Stabilization Time.

The time for the oscillator to stabilize in a $35^{\circ}F$ temperature environment after being in a power off state for 72 hours is given by the following:

TIME AFTER TURN-ON	FREQUENCY OFF-SET AND/ OR DRIFT RATE
1 hr	$\pm$ 2 parts in 10^8/day
8 hrs	$\pm$ 7 parts in 10^9/day
24 hrs	$\pm$ 2 parts in 10^9/day

2.1.1.3 Time Code Outputs.

Each of the GMT and MET accumulators is capable of generating serial time code. This time code is presented at the MTU output in two fashions:

A. Continually updated outputs at a rate of 100 pulses per second in modified IRIG-B format. The outputs consist of five independent different outputs of serial MET. These outputs will be used typically to provide time code to recorders, subcarrier oscillators and time display equipment.

B. Demand outputs which are read-out upon receipt of externally supplied enable signals. These outputs consist of seven completely independent serial analog outputs of GMT, BITE, and MET time code data. These outputs contain one word of BITE status, followed by three words of GMT and then three words of MET. These outputs are used typically to provide time code to pulse code modulation equipment and computers.

2.1.1.4 Reliability.

The MTU is constructed such that a first failure will not affect mission completion and a second failure will not affect mission safety. The BITE can check the overall integrity of the complete timing system. It can perform self-tests to determine if the system is 100 percent functional but it cannot fully analyze the nature of the failure. The BITE outputs signals denoting the first failure and a first failure followed by a second failure. The unit is designed such that it can still function after the first failure.

2.1.2 Pulse Code Modulation Master Unit

The function of the Pulse Code Modulation Master Unit (PCMMU) is to collect data from the operational instrumentation subsystem (OI), the payload data interleaver and five onboard General Purpose Computers (GPC) and format this data for output to the network signal processor, GSE umbilical and onboard recording system. It is also an interface device between the Orbiter GPC's and the Spacelab subsystem and experiment computers. The PCM MU also provides data storage and access to that data by the performance monitor system over any of the computer buses.

The PCM MU outputs both 64 KBS and 128 KBS multiplexed serial digital data to the network signal processor. Each output stream is formatted by its output formatter. Associated with these formatters are 3 format memories; 64 KBS software updatable, 128 KBS updatable and 128 KBS fixed. The software updatable memories provide the capability to load new formats from mass memory.

2.1.2.1 Timing Related Functions.

The PCM MU accepts a 4.608 MHz square wave clock pulse from the MTU. It divides the clock frequency as necessary to obtain all internal timing related to the generation of the 64 KBS and 128 KBS telemetry downlink data stream, the 1.152 MHz clock output to the Payload Data Interleaver (PDI), and the 100 Hz IRIG-B GMT clock output. The PCM MU has a 4.608 internal clock that can perform all functions of the MTU 4.608 MHz output in the event that this output is not present. In switching from the MTU 4.608 MHz clock to the PCM MU 4.608 MHz clock,

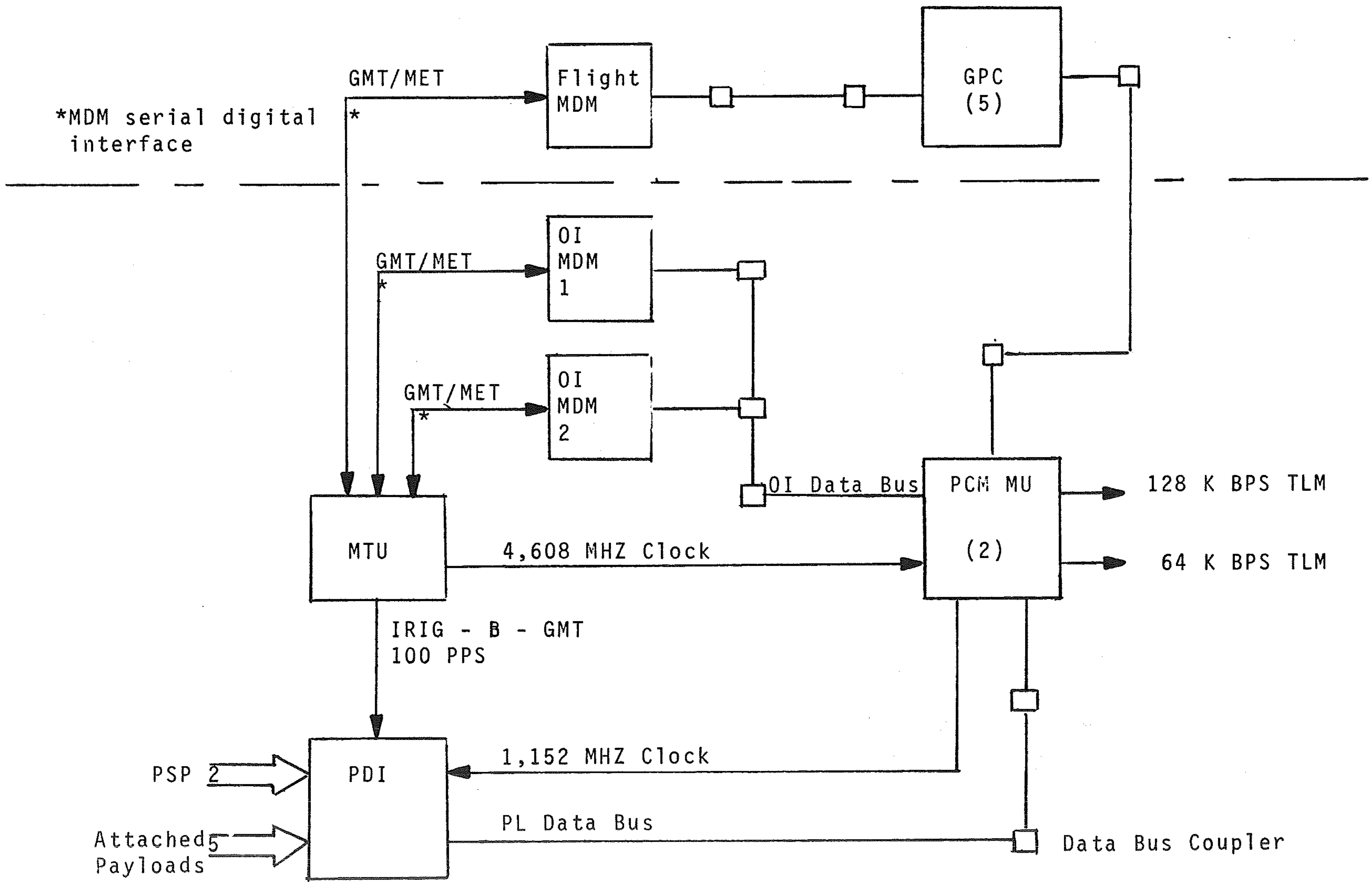


FIGURE 2-2 Instrumentation Subsystem

pulses could be lost. When this happens, the PCM MU frequency dividers are not reset, but will suspend their counting until the 4.608 clock pulses resume. As a result, a telemetry downlink format interruption could occur. The PCM MU clock has a frequency stability of one part in 10^6 over a sixty second period.

The role of the PCM MU is sketched in Figure 2-2. The PCM MU fetches MTU GMT (48-bits), MET (48-bits), and BITE (16-bits) at a rate of 5 samples/second from the MTU via the Multiplexer-Demultiplexers (MDM's) and interleaves these samples into the 64 KBS or 128 KBS downlink at a rate of 10 samples/second. The two MDM's are used for redundancy purposes. The PCM MU also fetches MTU GMT at 1 sample/second via the same MDM's for use by the GPC for initialization of the GPC software psuedo-synchronization to the PCM MU downlink telemetry format generation.

2.1.2.2 IRIG-B Data Skew.

As shown in Figure 2-2, the MTU 4.608 MHz clock pulses are routed to the PCM MU and the MTU IRIG-B GMT 100 PPS pulse is routed to the PDI. There is also a 1.152 MHz clock signal from each of the PCM MU's to the PDI. The PDI uses this 1.152 MHz (not synchronized to the IRIG-B pulse) for internal timing. The PDI has an internal 4.608 MHz oscillator (not slaved to the MTU) with a divide by 4 circuit which yields a 1.152 MHz clock from the PCM MU but loss of this clock (or delays exceeding a1.15 MHz period) will cause the PDI to switch over to its internal clock. Also, switchover from PCM MU1 to PCM MU2 will cause the PDI to switch over to its own 1.152 MHz clock until the PCM MU2 1.152 MHz clock is stabilized. Each switchover can cause an offset error of IRIG-B data by no more than 868 NS.

2.1.3 General Purpose Computer

The General Purpose Computer (GPC) provides the following capabilities for processing orbiter data: computation for the guidance, navigation and control subsystem, payload control for the manipulators, payload management, time keeping functions, and system performance monitoring for the Shuttle orbiter. This section will address the time keeping functions of the GPC.

2.1.3.1 GPC Time Keeping

There are five GPC's aboard the Orbiter, all of which can perform timing related functions. Each GPC has two program setable real-time clock registers capable of being incremented from either an external clock source and/or the GPC internal clock oscillator. The interval to be measured by clocks 1 and 2 should be at least 2 seconds. Each GPC clock keeps internal GMT and Mission Elapsed Time (MET) with a resolution of at least one microsecond. The GPC to MTU and MTU to GPC time words have a resolution of 0.125 milliseconds. The GPC will update its clock times about once each second using the MTU, providing that the MTU passes the redundancy management tests. These tests are based data from the three MTU registers, BITE, etc., and on-clock times from each of the four primary GPC's obtained via the computer to computer interfaces. Each GPC updates itself every 960 ms using the first source shown below that is within tolerance to the GPC GMT: MTU accumulator 1, MTU accumulator 2, MTU accumulator 3, internal time of another GPC, and self time (no update). Thus, a failed GPC clock will cause that GTC to be failed by the others without pollution. However, the crew can command a change to the first source alternative. The accuracy of GPC internal time versus MTU time while using the MTU updates is as follows: the maximum difference amoung GPC's is 92μs; the maximum GPC versus MTU difference is 235μs. These differences are valid only for a normal GPC environment. Error messages advise the crew and ground of MTU indicated problems or a GPC selected source change.

GPC timing and initialization is as follows. The first GPC initializes GMT and MET from the MTU unless the backup system has control, in which case, the GPC uses GMT and MET from the PCM MU. Subsequent GPC's initialize in coordination with those GPC's running. The GMT and MET can be updated by crew command, by launch data bus or uplink equivalent. Updates to the GMT should be limited to a maximum of 15 milliseconds since the updates cause the GPC to think it has a work backlog or lead. If the cumulative GMT updates exceed approximately 15 milliseconds, the downlist will be shifted in the window of the downlink. An option for updates of magnitudes of greater than 15 milliseconds is to go to OPS zero, which is an idle mode of the GPC, and update GMT. The GPC does not use MTU MET, instead MET is computed from GMT. Any MET update can be accommodated at any time. The GPC logs the GMT of liftoff (which is called MET reference). The crew can display MET (not MTU MET) which is the difference between the GMT_{LO} and the current GMT. This MET can also be downlisted; however, should the crew elect to display GMT onboard, GMT would be downlisted in the MET word slot. The GPC GMT is in every data cycle header (once per second) of all downlist formats and consists of two 16-bit words of binary microseconds, modulo one-half hour and one 16-bit word of half hours. The GPC GMT is the start of a minor cycle rather than the time any data was computed or obtained by the GPC. The downlist (GPC to PCM MU) is sent one minor cycle (40ms) after loading. When switching between PCM MU1 to PCM MU2, the effect is similar to GMT update of greater than 15 milliseconds and the loss of data can be from two to five seconds until the ground can get a valid frame of data.

2.2 ORBITER/SPACELAB TIMING INTERFACE

The Orbiter MTU provides pulse duration modulated time code signals and square wave clock signals to Spacelab. Two modified IRIG-B time code signals are also provided, one containing GMT, and the other containing MET, each of which shall be updated once per second. The absolute GMT time data does not deviate by more than ± 10 milliseconds from the ground station GMT Reference Time Standard at any time during a 7-day mission, and is synchronized with the ground GMT at certain times during mission, subject to mission procedural constraints, to prevent unacceptable time base perturbations. The MET will be reset to zero by the Orbiter at T-0 and shall be synchronized and updated from the ground.

A more detailed description of the Orbiter Time Distribution System is presented in paragraph 2.3.3.

*See reference 11 for an explanation of IRIG formats.

2.3 Spacelab Timing System.

In this section the function of various components of the Spacelab Timing System are discussed. Experiment data time tagging methods are also discussed.

2.3.1 High Data Rate Acquisition Assembly.

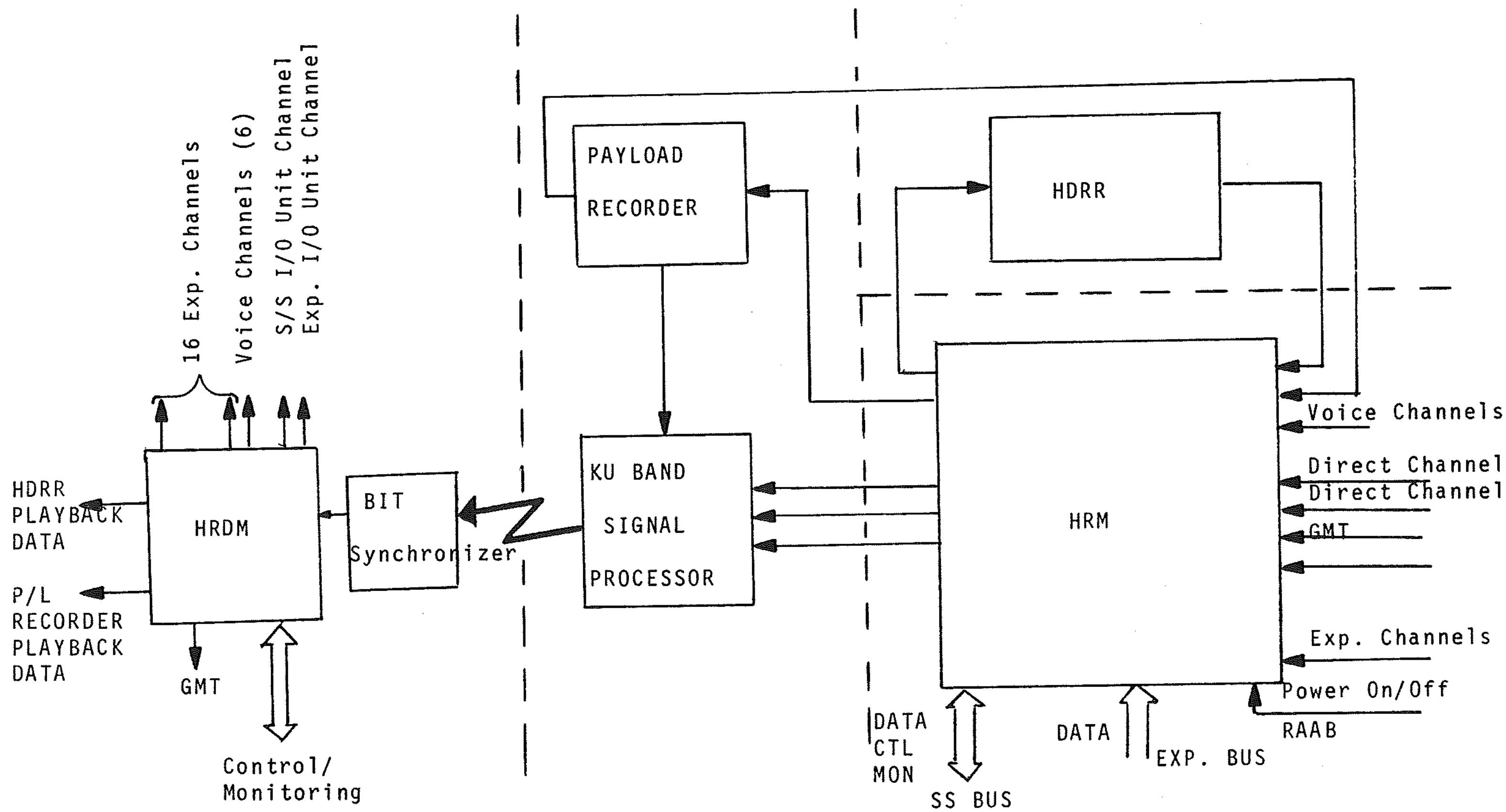
The High Data Rate Acquisition Assembly (HDRAA) is used to collect on-board Spacelab experiment data and to time multiplex those data together with IRIG B Time, I/O Outputs, Playback Data from on-baord recorders, and digitized voice. The multiplexed signal is then serially transmitted to the ground via the orbiter KU Band signal processor, received by the ground station receiver, including bit synchronizer, and demultiplexed to recover on ground the same channels as presented on-board at the inputs. Figure 2-3 is a block diagram of HRAA.

2.3.1.1 High Rate Multiplexer.

Since the High Rate Multiplexer (HRM) represents the core of the HDRAA, the tasks of the HRM are not constrained to the actual data multiplexing. The HRM also controls the data routing within the on-board part of the HDRAA, it performs the voice digitizing and GMT decoding, and it provides electrical interface circuits to the on-board interlinking equipment. A block diagram of the HRM is shown in Figure 2-4. The HRM is designed to:

A. Accept:

- o 16 switchable channels from the experiments.
- o 2 direct channels from the experiments.
- o 1 input from the High Data Rate Recorder (HDRR).



H.R.A.A. BLOCK DIAGRAM
Figure 2-3

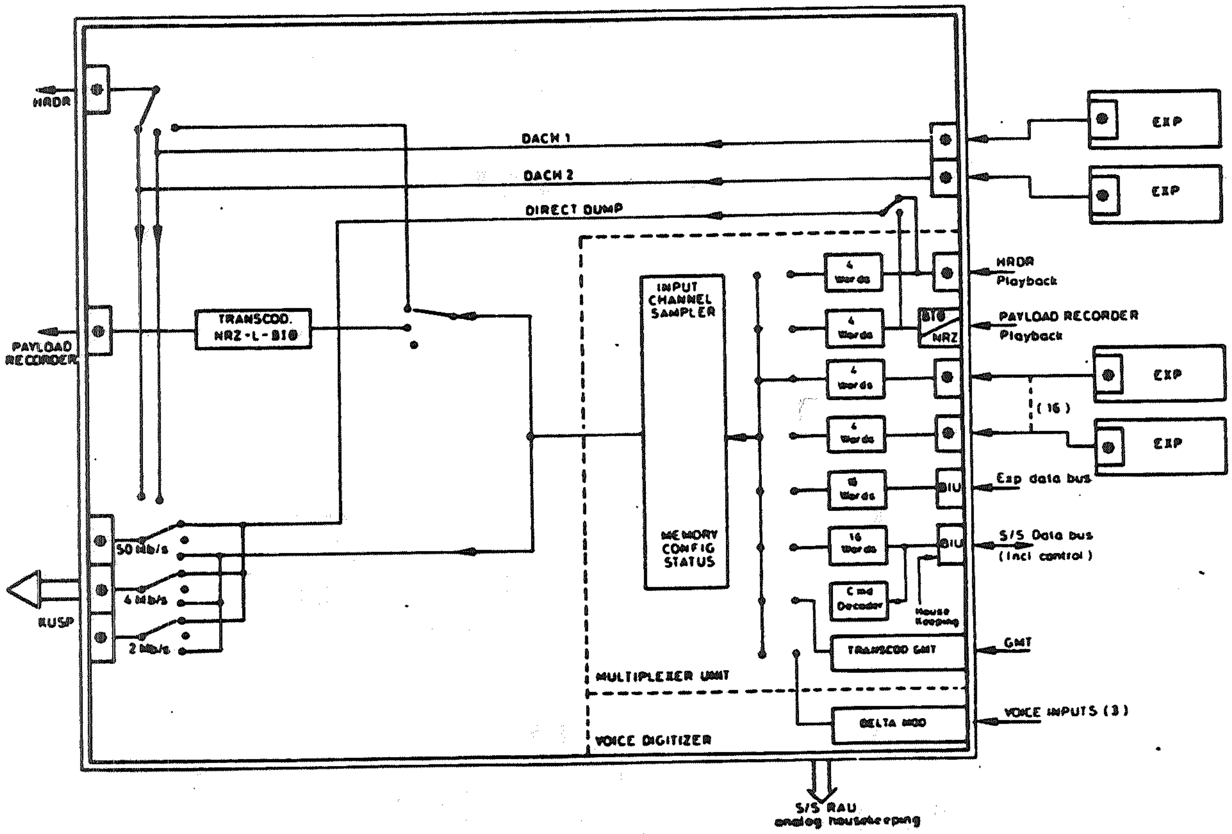


Figure 2-4 HRM Block Diagram

- o 1 input from the payload recorder (PLR).
- o 2 data channels from the input/output unit (I/O's).
- o 1 GMT signal from the Remote Amplifier and Advisory Box (RAAB).
- o Commands from the Subsystem I/O through the Subsystem Bus.
- o 3 analog channels from the voice intercommunication system.

B. Multiplex and/or transmit directly all or part of its inputs to the outputs listed below, depending on the chosen modes.

C. Output signals to:

- o Orbiter KU Band Signal Processor (KUSP)
- o Orbiter payload recorder for medium rate recording
- o Spacelab high data rate recorder for high rate recording
- o Remote Acquisition Units (RAU) for monitoring purposes.

2.3.1.1.2 MULTIPLEXING CONCEPT.

The HRM collects serial data from different sources performs a time division multiplexing based on 16-bit time intervals and, finally delivers an output on one serial data stream containing all the input data.

The main characteristic of the concept employed is the capability to accept serial data that are completely aschronous with respect to the HRM internal clock. The decoupling of the input clock from the HRM internal clock is performed by means of 4 X 16 bit buffer.

In a sequence determined by the HRM format loaded, the format controller fetches one 16-bit word out of the input buffer and transfers it to the HRM output register, where it is serialized. In the case of an empty buffer, a fill word is introduced, which can be identified as such by means of the fill identification as a part of the frame overhead. During demultiplexing on ground, the fill words are automatically suppressed.

Only two constraints are imposed on input data by this method:

o The input bit rate averaged over any sequence of 64 bits shall not be higher than the nominal data rate allocated. The nominal data rate is determined by the HRM formal selected. If the input bit rate is higher, the input buffer will overflow. Overflows are announced to the Subsystem Computer.

o The peak bit rate shall not be higher than 16 MB/S. This constraint is due to the hardware limitation of the HRM input circuits.

Serial data delivered to the HRM will be recovered on-ground from the HRDM completely unchanged. This means that the user himself has to take care of formatting and structuring of his serial data. To facilitate this task, each HRM experiment channel can operate in two different modes as follows:

NORMAL MODE.

In this mode, the word structure in the HRM output frames are not at all correlated with any structure of the input data. The serial data is arbitrarily chopped into 16-bit words for parallel processing inside the HRM. Consequently, the user has to insert some kind of sync pattern into his serial input bit stream in order to be able to extract on ground his scientific data out of the serial bit stream of his output channel.

WORD TRANSPARENCY MODE*.

In this mode, the input data can be structured into words that, after multiplexing, can be identified as words in the HRM output frames in those positions determined by the chosen format. Synchronously with the frame or format pulse, which indicates the beginning of a new frame or format respectively, experiment data can be delivered to the HRM in bursts of 16-bit words. Because the clock counter is reset at the beginning of each format, these words are identical to the internal words the HRM handles in parallel.

*This mode is under review and could be deleted.

In this mode the HRM delivers the data words without bit rate smoothing at the nominal bit rate allocated to the particular experiment channel. The mode (normal or word transparency) of each input channel is determined by an external HRM connector. This connector is programmed by hardwired jumpers on a mission-to-mission basis.

2.3.1.2 HIGH RATE DEMULTIPLEXER.

The High Rate Demultiplexer (HRDM) is the complimentary part of the HRM in respect to the functional performance and the type and number of output channels. It provides on-line and off-line decommutation of the data stream received on ground via the TDRSS link. A block diagram of the HRDM is shown in Figure 2-5.

The HRDM is designed to:

A. Accept:
   - o 1 serial stream of data from the bit synchronizer.
   - o commands from the ground computer system.

B. Demultiplex and/or transmit directly , depending on the mode, data to the following outputs:
   - o 16 experiment channels (200 B/S to 16 MB/S)
   - o 1 HDRR channel (2/4/8/12/16/24/32 MB/S)
   - o 1 payload recorder channel (1 MB/S)
   - o 2 I/O channels (200 B/S to 0.5 MB/S)

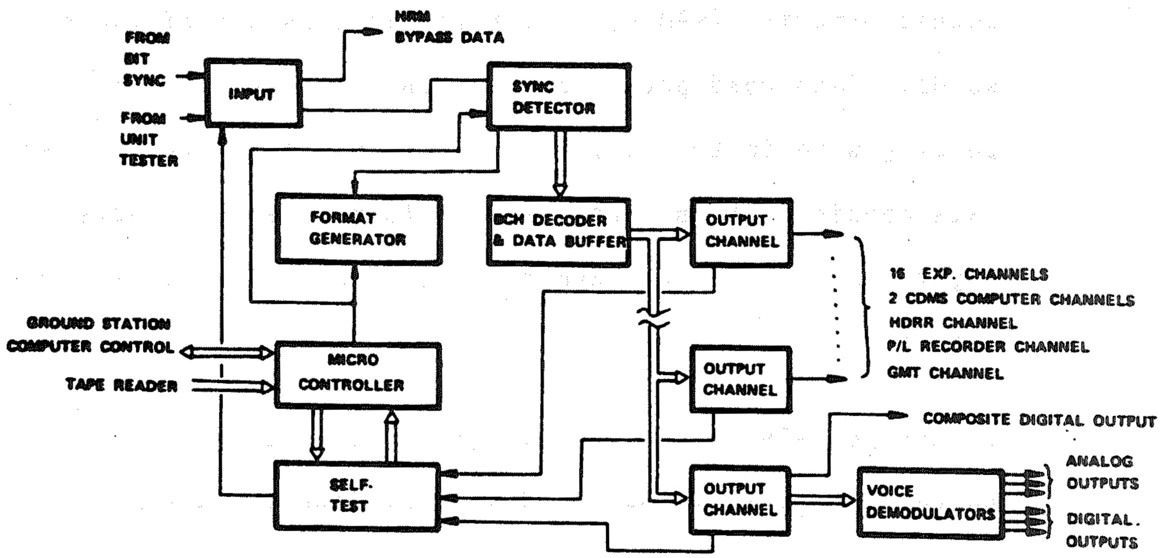


Figure 2-5 HRDM Block Diagram

- o GMT signals
- o Voice channels (3 analog, 3 digital)

2.3.1.2.1 DEMULTIPLEXING CONCEPT.

The format generator stores up to 16 formats in programable read-only memories (PROM's), plus two formats in random access memories (RAM's). Each format consists of 768 8-bit words. Each word presents the channel address of the corresponding word in the format. One frame of the HRDM input data consists of 96 words, so one format repeats every eight frames. The two RAM's can be loaded from a ground computer.

In the Bose-Choundhuri-Hocquenghem (BCH) decoder and data buffer, the data is buffered line-by-line and the fill identification word is decoded. Each line is then decommutated, fill words are removed, and the detected data is sent to the appropriate output channel buffer.

The output buffers consist of first in first out (FIFO) memories capable of storing 64 16-bit words. Data is loaded in parallel into the FIFO from the BCH decoder and data buffer as it is available from the input data stream. The data words automatically bubble through the buffer from top to bottom. The data is removed from the FIFO at the appropriate rate to acheive the programmed output bit rate for every channel.

2.3.1.2.2 OUTPUT MODES.

Two output modes can be selected: continuous around a programmed bit rate (±1 Percent), and burst mode.

In the continuous mode, the HRDM provides a smoothing of the output data stream that otherwise might have gaps caused by commutation of other channels. The clock regulator checks whether the contents of the buffer is more or less than 32 words. This information is input to a micro-processor that can adjust the clock-out frequency to within ±1 percent.

In the burst mode, the clock regulation is disabled. The data is clocked out at a fixed predetermined frequency as it is decommutated. Time delays are caused only by the intermediate line-by-line buffering and the output buffer bubble-through line which is about 2 μS.

The selection of the output bit rate of and the mode for each channel is part of the format selected.

2.3.2 Remote Acquisition Unit.

The Remote Acquisition Units (RAU's) are the principal interfaces for the bidirectional link between experiments and the Command and the Data Management System (CDMS) for acquisition of low bit rate digital data, analog data and distribution of commands.

2.3.2.1 Functional Concept.

The data exchange between RAU's and the I/O unit is performed via simplex serial buses with 1 Mb/s clock rate. The data are encoded in a self-clocking biphase code (Manchester II). Each experiment RAU incorporates the following user interfaces:

A. Inputs.

- o 128 flexible differential inputs for analog or discrete signals.
- o 4 serial PCM data channels with associated clocks, code NRZ-L.

B. Output.

- o 64 ON/OFF command channels
- o 4 serial PCM command channels with associated clocks, code NRZ-L
- o 4 User Time Clock channels (1024kHz)
- o 4 User Time Clock Update channels, 4 pulse cycles/s.

A block diagram of the RAU is shown in Figure 2-6.

The RAU data acquisition is based on a software controlled concept. The software for subsystem data acquisition and control is provided by Spacelab. The software for experiment data acquisition and control has to be provided by the experimenter in accordance with his requirements. Applicable portions of the Spacelab software can be used by the experimenter.

The RAU's will be scanned periodically with basic periods of 10 ms, 100 ms, or 1 second. Each scan cycle will be initiated and controlled by the General Measurement Loop which is part of the Spacelab computer software. The experimenters may design their own software to generate additional measurement cycles using the operating system task scheduler. This scheduler will accept priority levels and queue up experiment software requests for data and command transmission.

2.3.2.2 Physical Concept.

Thirty-two different addresses are foreseen for the RAU's on a bus. The address for a particular RAU is determined by a patch connector. For electrical reasons the buses (S/S and experiment bus) are split into two branches, causing a split of the 32 RAU addresses on each bus.

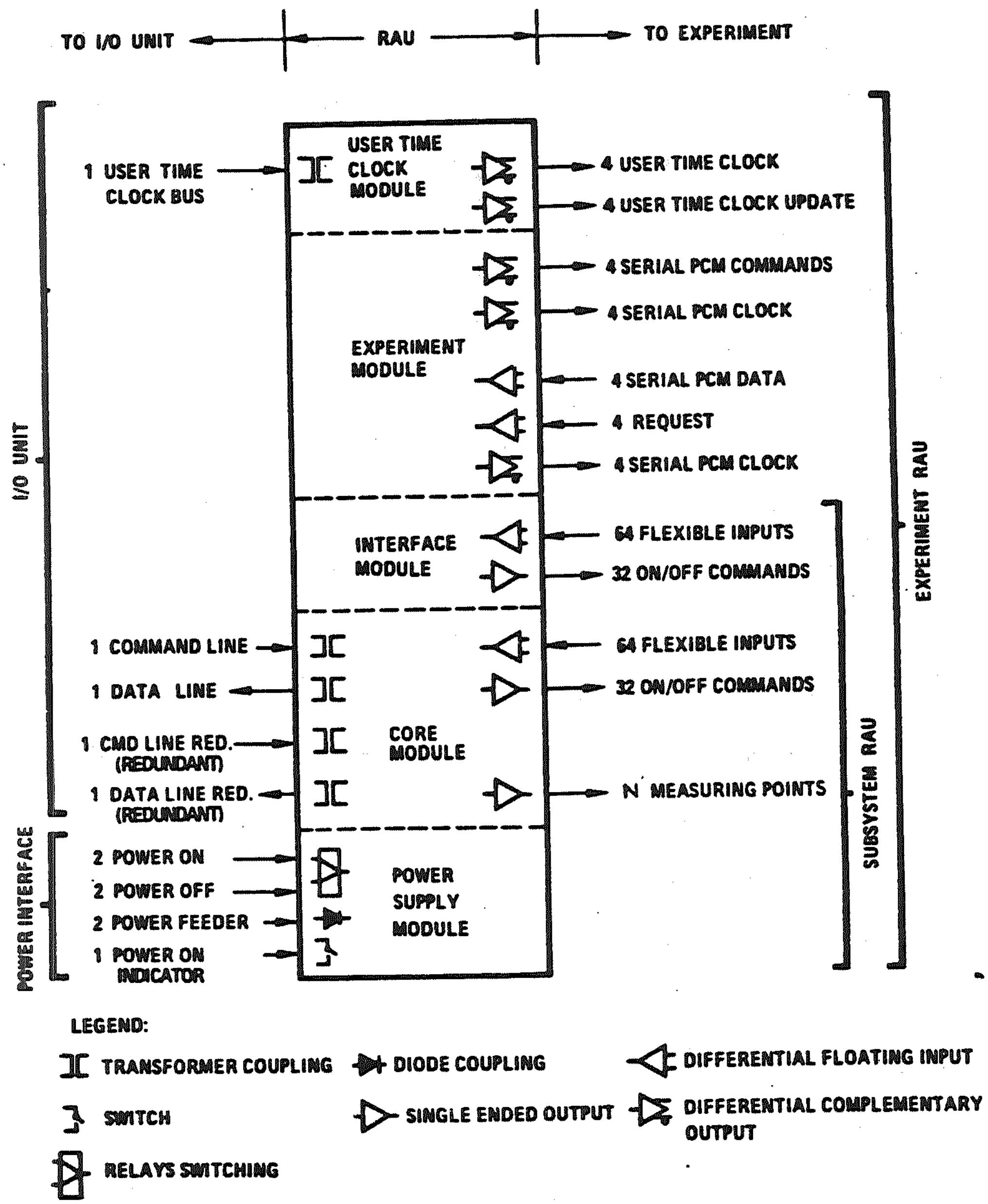


Figure 2-6 RAU Block Diagram

The split for the S/S bus is:

- o AFD branch, addresses 0-7 (including IPS S/S RAU's)
- o Main branch, addresses 8-31.

The split for the experiment bus is:

- o Airlock branch, addresses 0-7 (including IPS experiment RAU's)
- o Main branch, addresses 8-31.

The electrical characteristics of the buses allow the accommodation of up to 22 RAU's per branch. Eight experiment RAU's is the total number of units delivered by the Spacelab program.

Experiment RAU's can be connected to the experiment data bus at a number of interconnecting stations (IS's) in the module and on each pallet. There are two interconnecting stations in the core segment, three in the experiment segment, and two on each pallet segment. Each station accommodates two RAU's.

The Spacelab baseline provides standard locations for RAU's in the lower part of the experiment racks. However, the concept allows the user to integrate RAU's together with his experiment equipment, if he uses his own racks and/or experiment equipment mounted directly to the center aisle or to the pallet. In every case the user has to ensure that the cable length between RAU and IS is less than 5 meters, and that the applicable interface specifications of the RAU are met in accordance with EQ-MA-0003.

There are two different types of RAU. The smaller type is the subsystem RAU consisting of the power supply module, core module, and the interface module

The larger type is the experiment RAU consisting of the subsystem RAU modules plus the experiment module (which provides serial PCM input and outputs) and the User Time Clock (UTC) module. The functions of the RAU are described in the subsequent paragraphs.

2.3.2.3 RAU - Experiment Link.

The RAU - Experiment Link is broken down into two cases: data transfer from RAU to the experiments and data transfer from the experiments to the RAU.

2.3.2.3.1 Data From RAU To Experiments.

The data transfer from the RAU to the experiments comes from the following three sources:

A. Serial PCM Command Channel.

Four RAU channels can deliver serial PCM commands to the experiments, in connection with four RAU provided

1 MHz clock pulses. The code is NRZ-L. The maximum command exchange per software requested transaction will be thirty-two 16-bit-words (plus parity bit). The time gap between each two transmitted words will be 3μs. In addition to commands to control experiment functions, the user may receive via this link additional software generated information such as GMT, MET, ground data, Orbiter state vector, etc.

B. <u>On/Off Commands.</u>

Each RAU will provide 64 On/Off commands as constant voltage levels to the experiments. These outputs may be used to set or reset experiment functions. Each On/Off command output has to be individually addressed by the computer software. The load capability of these RAU outputs is designed to drive opto-couplers directly.

C. <u>User Time Clock Outputs.</u>

The experimenter can receive timing information from the RAU UTC module. A 1024 kHz clock (duty cycle 0.5) and an update pulse group (every 250 ms) are available. These signals are derived from the master oscillator in the Orbiter MTU and are therefore synchronized with GMT within the accuracies of the count-down electronics chains of the Orbiter MTU.

2.3.2.3.2 Data From Experiment To RAU.

The data is transfered from the experiments to the RAU from the following two sources:

A. Serial PCM Data Channel.

Four RAU channels are available to transfer NRZ-L coded serial PCM data from experiments via RAU to the computer. Each channel consists of a data line, a clock line, and a request line. The RAU will accept from the experiment 17 bit words, including a user generated parity bit as long as the user provides a logic one level on the request line. However, an internal timer in the RAU will restrict the number of serial data words accepted to a maximum of 32. If the request line level changes from one to zero during the transmission of a word, all 17 bits of this word will be accepted by the RAU and transmitted to the computer. Each serial PCM data channel will provide the user with a 1 MHz clock signal to read out the data contained in the experiment buffers. With appropriate software it is feasible to announce the request for serial PCM data by an On/Off command to the experiments. NOTE: The parity bit is assigned to a value that makes the number of ones in each 17-bit word an odd number. The status (one or zero) of the experiment provided serial PCM data request lines may be scanned by the RAU on a special software request and transferred to the experiment computer. In this special case the four request lines will be handled like discretes.

B. Flexible Inputs.

The experiment RAU provides 128 flexible inputs. The electrically identical differential inputs can be programmed to accept either:

- o Discrete input signals (i.e., one bit of parallel digital data)
- o Analog input signals which are digitized in the RAU.

The use of flexible inputs as analog or discrete channels is determined by the actual software request (i.e., in principle each flexible input may be changed from analog to discrete or vice versa between two subsequent software acquisition commands). However, in the case of discrete data acquisition only, blocks of 16 inputs are addressable. Thus 16 bits in parallel are accepted and, after addition of one parity bit in the RAU, they are serially transferred to the computer via the I/O unit. The number of 16-bit blocks accepted during one scan cycle is software controlled and may vary from 1 to 8. In the case of analog data acquisition, two adjacent input channels (analog single mode) or blocks of 16 input channels (analog scanning mode) are addressable. The selection of the acquisition mode is software controlled.

The analog/digital conversion has a resolution of 8 bits; thus the conversion of signals in two adjacent input channels leads to a 16-bit word. This word, after addition of one parity bit, is sent via the serial data bus to the I/O unit. In the analog scanning mode up to 64 words per software request can be transmitted to the I/O unit.

2.3.2.4 <u>I/O Unit - RAU Link.</u>

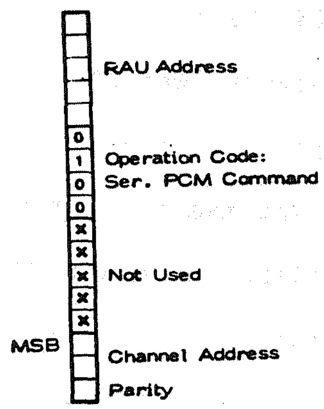
The experiment RAU's are linked to the I/O unit by the experiment bus. The data bus consists of a simplex command line which carries instructions and data from the I/O unit to the RAU's and a simplex data line which carries responses and data from RAU's back to the I/O unit. The data bus and the interfaces at the I/O unit and the RAU's are dual redundant. Instructions and data are transferred at 1 Mb/s in 16-bit plus parity words in Manchester II (Biphase-level) code. Each word is preceded by a 3 μs nonvalid Manchester synchronization signal.

An additional "clock bus" is also provided which distributes the MTU derived 1024 KHz clock and update pulses from the I/O unit to the experiment RAU's for the user. The data bus and the RAU/bus interface is dual redundant. The subsystem bus connecting the subsystem RAU's to the subsystem I/O unit is similar to the experiment bus except that the "clock bus" is not provided. The I/O unit - RAU link can be broken down further into two parts: command transfer and data transfer.

2.3.2.4.1 Command Transfer.

A. Serial PCM Commands.

The transfer will start with a sync pattern and an instruction word followed by the inverted sync and the inverted instruction word. The instruction word includes RAU address, operation code, and channel address as sketched below. After the acceptance of this message the RAU will send back an acknowledgement sync to the I/O unit (time delay < 10 μs). The I/O unit now starts the transmission of command information as 16 bits + parity data words as a block with a maximum of 32 words per transaction. Each word is preceded by an inverted sync pattern and the end of the block is indicated by a noninverted sync (EOT).



The RAU will check the received data words by checking the sync, the Manchester code pattern, and the parity while transmitting them to the experiments. In the case of an error, the RAU will shut down its output immediately. Otherwise it will send back an acknowledgment sync to the I/O unit after receiving the EOT sync (time delay $< 5\mu s$).

B. On/Off Command.

The transfer will start with a sync signal followed by the inverted sync and the inverted instruction word. The instruction word contains the RAU address, operation code, one bit indicating the level to which the On/Off output of the RAU has to be set, and the binary coded channel address.

2.3.2.4.2 Data Transfer.

A. Serial PCM Data Inputs.

The transfer of serial PCM data from an experiment via RAU to the I/O unit will be initiated by a software generated instruction word on the command line. After receiving this word, the RAU will check the status of the request line of the addressed serial PCM data channel. If the status of the request line is detected as zero, the RAU will send back a sync signal to the I/O unit within a maximum time delay of 10μs.In this case, the computer system will stop the dialogue for this channel or repeat the transfer of instruction words as determined by software. If the status of the request line is detected as one, the RAU will start to deliver clock pulses to the experiment within a time $<$ 2.5 μs. These clock pulses are grouped in blocks of 17 pulses and separated by a 3-μs time gap. Each block will take 17 μs and will be used to read out one 17-bit word from the experiment buffer. (The 17th bit always has to be the experiment-generated parity bit.) The RAU will continue to deliver these clock pulses as long as the status of the request line is one, the number of words transmitted from the experiment to the RAU is not greater than 32, and no parity error is detected in the user's data words.

The data words received by the RAU will be processed and transmitted to the I/O unit in real time. Processing includes a check of each parity bit, conversion from NRZ-L to Manchester II (Biphase-level) code, and the generation of sync signals at the beginning of each data word and at the end of the data transfer.

There exists another possibility to scan the status of the RAU request lines for serial PCM data inputs. The request line scan may be of advantage for experiments using several RAU input channels for serial PCM data with randomly distributed acquisitions times. The dialogue between I/O unit and RAU for scanning the request line status of four channels of one RAU will take a maximum of 53 μs, while the data acquisition mode described above will need at least 132 μs to check four channels with request lines having zero status.

The dialogue will start with a sync signal and an instruction word transmitted by the I/O unit on the command line. After a maximum delay of 10 μs, the RAU will answer with a data word preceded by an inverted sync signal and followed by a sync signal. Four bits of this data word (one for each channel) will contain the status of the request line.

B. Flexible Inputs.

The acquisition of analog signals (analog mode) as well as parallel digital data (discrete mode) is performed via the flexible inputs.

1. Analog Data.

The instruction word includes RAU address, RAU channel, or block address, and operation code. Included in the operation code is the information to acquire analog data and the sampling mode. Two modes are possible:

a. Analog Single Mode.

This mode allows the sampling of two adjacent channels. The binary RAU channel address in the instruction word has to be even and may be in the range from 0 to 126. The digitized analog signal of the addressed channel and the next following one will be transmitted to the I/O unit.

b. Analog Scanning Mode.

This mode samples blocks of 16 input channels. The number of blocks acquired per software request is determined by the user and may vary from 1 to 8. This information is contained in the instruction word in an N of 8 code.

Each block address is directly correlated to 16 flexible hardware inputs. The correlation between hardware inputs and software channel and block addresses cannot be changed by the user. After receiving the instruction word, the RAU initializes the 8-bit analog/digital conversion. The digitized signals of two input channels form a 16-bit word, The RAU adds a parity bit, encodes the word, and starts the transfer to the I/O unit less than 20μs after receiving the instruction word. As the analog/digital conversion circuitry consists of two sample and hold units and a fast ADC, there will be no time delay in addition to the transmission time determined by the RAU-I/O unit dialogue.

2. Discrete Data.

This dialogue starts with a software-generated instruction word which is sent on the command line to the RAU.

The smallest unit which may be sampled is a block of 16 discrete inputs transferred as 16 bits plus a parity bit per word via the data line to the I/O unit. The number of blocks transmitted per software request may range from 1 to 8. The correlation between software block address and pin allocation of the RAU and I/O unit is completed by an RAU-generated sync on the data line.

2.3.2.4.3 RAU Test Modes.

The RAU is designed to check the performance of the received data. This applies to the instruction and data words from the I/O unit and the serial data words from the experiment. In addition, the I/O unit will check the data words from the RAU.

Data and instruction words from the I/O unit and RAU data words sent to the I/O unit have to fulfill the following criteria:

o Word transmission at 1 Mb/s bit rate

- Manchester II coding properties
- Each word must consist of a sync (or $\overline{\text{sync}}$) + 16 data bits + parity bit
- Valid operation code (applicable to instruction words only)
- Odd parity of each word.

If a word does not fulfill one of these criteria, the word is considered invalid and will not be accepted by the receiving unit. In particular, the RAU will stop its work and the error will be indicated in the RAU internal status word by bit No. 12, which is set to logical level one. In addition, the RAU will not send back to the I/O unit an acknowledge sync signal or an end of transmission signal.

After the error has been detected, the I/O unit (or more precisely the RAU-coupler of the I/O unit) repeats either the whole sequence, if the failure is related to On/Off commands or acquisition of data via flexible inputs, or the instruction words only, if the failure is related to serial PCM commands or serial PCM data acquisition.

If the repetition has no success, the RAU-coupler of the I/O unit will initiate a self test. The RAU internal status word will be acquired by the I/O unit. The results will be analyzed to decide whether to switch over to the redundant part of the experiment CDMS data bus (including the redundant bus interface units) or to switch off the RAU.

Experiment data words at the RAU input will be checked only with respect to the experiment-generated odd parity bit. If a parity error is detected, the RAU will stop sending bit shift pulses to the experiment. In addition, no end of transmission (EOT) sync will be sent back to the I/O unit, and bit No. 11 of the RAU internal status word is set to level one. In contrast to the traffic on the data bus, there is no automatic self test related to parity errors in the experimenters data; therefore, the user should acquire this status word periodically by his own request.

A more detailed test, including a check of the RAU analog to digital converter will be performed only on a user's request.

RAU internal status word acquisition is as follows. The dialogue starts with an instruction word on the command line. Within less than 20μs, the RAU will return a data word containing the following:

A. Bits 0-4.

This is the RAU address.

B. Bit 5, Primary Power Breakdown.

The primary power voltage will be checked for under-voltage below 24 V during a period longer than 500μs. The bit 5 will be set to one when the primary power recovers the normal range. This bit will be reset to zero by the acquisition of the internal status word, and will keep this state if no voltage drop occurs. If no failure occurs, bit 5 will show one level for the first internal status acquisition, and always zero for the following acquisitions.

C. Bit 6, UTC Status.

This bit will be set to one in the case of complete or momentary absence of UTC signal coming from the I/O unit. This bit will be reset to zero after internal status word acquisition.

D. Bit 7, Experiment Module On/Off Status.

This bit is set to one if the RAU experiment module is powered.

E. Bit 8, Interface Module Correction Status.

This bit is set to one if the RAU interface module is physically connected and powered.

F. Bit 9, On/Off Command Status Of The Core Module.

This bit, set to one, will indicate that the On/Off command boards in the core module are energized.

G. Bit 10.

This bit, set to one, will indicate that the On/Off command boards of the interface module are energized.

H. Bit 11, Serial PCM Input Channel Status.

This bit is set to one if, on any of the four serial input channels of the RAU, the serial PCM clock is not working properly, the user words show wrong parity, or the nominal time for transferring 32 user data words has elapsed (timeout). This bit is reset to zero after each acquisition of the status word.

I. Bit 12, I/O Unit - RAU Data Link Status.

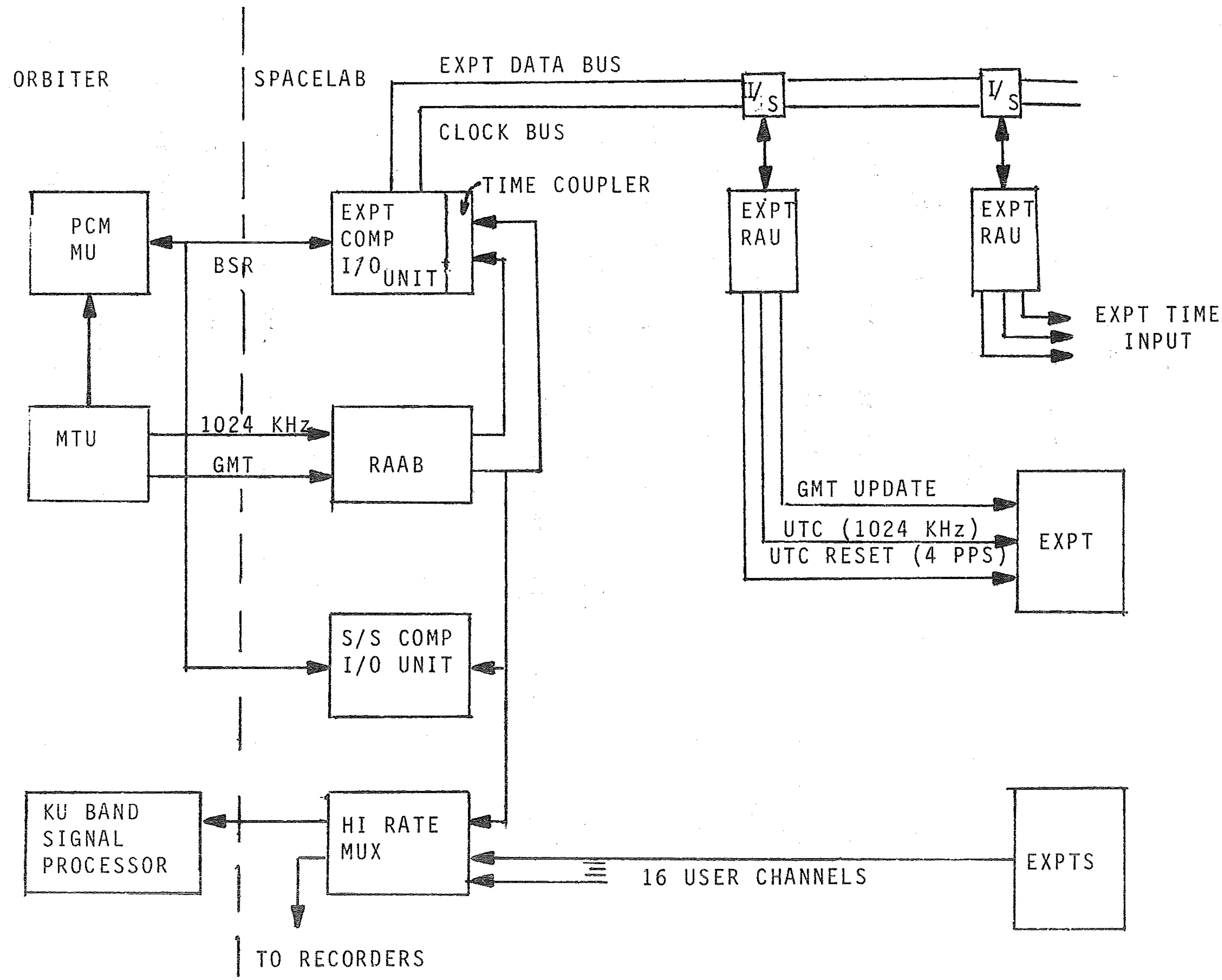
This bit is set to one if the RAU detects an error in the serial data incoming from the I/O unit. After each acquisition of the status word, the bit is reset to zero.

J. Bits 13-15.

Spares.

2.3.3 SPACELAB TIME DISTRIBUTION SYSTEM

This next section addresses the distriubtion of time through out the Spacelab. Figure 2-7 is a block diagram of the Spacelab Time Distribution System. The Orbiter MTU is the source of all time signals distributed to Spacelab. The Remote Amplifier and Advisory Box (RAAB) is the interface between the Orbiter MTU and the Spacelab elements. The MTU GMT and 1024 KHz clock signals are routed through a RAAB to the experiment I/O time coupler. The 1024 KHz clock signal is called the Users Time Clock which should not be confused with the UTC (Universal Coordinated Time). The time coupler generates the Users Time Clock update, which is a 250 millisecond signal derived from the 1024 KHz clock signal, forming a composite clock signal. The MTU GMT is routed to experiment RAU's (Remote Access Units) via the experiment data bus. The composite clock signal is routed to experiment RAU's via the experiment data bus. The RAU demodulates the composite clock signal and routes the Users Time Clock (1024 KHz), Users Time Clock reset (4 PPS) and GMT to the experiments. The experiments get a GMT update message which is the calculated value of GMT at the next Users Time Clock reset signal (every 250 milliseconds). The 1024 KHz and GMT paths, as well as the time coupler, are not redundant on the spacelab side. The exact impact on the experiments due to a loss of GMT and/or 1024 KHz



SPACELAB TIME DISTRIBUTION SYSTEM
FIGURE 2-7

clock signal are not known at this time; however, the experiment computer generates an internal timeword which is made available to the experiments upon loss of GMT.

The GMT from the RAAB is also routed to the subsystem I/O and HRM (High Rate Multiplexer); however, they do not receive the 1024 KHz clock signal. Some experiments, which do not downlink data in the Orbiter Interface, will have neither the MTU GMT nor the 1024 KHz clock signal. Since the experiments will downlink data via the HRM, there will be a time error between the experiment and HRM GMT associated with a frame of data. The magnitude of this error is not known at the present time.

2.3.4 SPACELAB TIMING ACCURACY

The long term drift of the MTU will be 1 X 10^{-9}/day giving an accuracy better than 3 ms over a 7 day mission. The deviation of the onboard time from ground time will be controlled and logged on ground with an accuracy of better than 1 ms. If the deviation is more than $\pm$10 ms, the Orbiter MTU will be readjusted externally. From the Orbiter MTU, two different time signals are delivered to spacelab and are available for experiment time tagging:

A. The GMT serving as "macroscopic"time information. This has a resolution of 10 ms. It can be distributed to experiments via the RAU serial PCM command channels. The GMT is also inserted into the HRM data frames, thus providing automatically a macroscopic time tagging of experiment data acquired by the HRM.

B. The 1024 KHz User Time Clock serving as "microscopic" time information. The User Time Clock has a time resolution of 1 μs. It is distributed hardwired to the experiments via the RAU UTC channels.

A direct interface to the Orbiter MTU, other than through the Command and Data Management System, is also available to the experiments. The time delivered is the Mission Elapsed Time. This time information is delivered in a modified IRIG-B format, i.e., a pulse width modulated pulse train (100 pulses per second) contains the binary coded decimal information in seconds, minutes, hours, and days. The IRIG-B format is modified so that the "straight binary seconds" which begin at Index Count 80, will not be generated. The IRIG format will be modulated with a 100 pulse per second output rate and will have a resolution of 10 ms.

2.3.5 TIME TAGGING METHOD

As previously mentioned, the spacelab time distribution system is designed to provide an accuracy of better than

10 μs relative to the MTU. This is accomplished by the following method. The MTU 1024 KHz signals are routed through the RAAB to the time coupler in the experiment I/O unit. The time coupler generates the User Time Clock update which is a 250 ms signal derived from the 1024 KHz clock. This is done by:

- o Incrementing an 18 bit counter which is reset every 250 X 1024 pulses.
- o Forming a composite clock by modulating the 1024 KHz clock every 250 ms , 8 pulses before the counter is reset.

At the RAU level, the composite clock signal is demodulated in order to provide the two signals User Time Clock (1024 KHz) and UTC update (four pulses long, sync every 250 ms). The end of the UTC update sync pattern is correlated to the 18 bit counter reset.

The time coupler also performs the correlation between the UTC update and the GMT. Every 250 ms, synchronously with the GMT, the 16 most significant bits (MSB's) are loaded into the correlation register. This 16 bit word θ represents the correlation between GMT and UTC update with an uncertainty of 4 μs because the last two bits of the 18 bit counter have been dropped. Both the decoded GMT and θ are transferred periodically via the time coupler buffer into the experiment computer. Appendix C explains the functions of the Time Coupler and computation of θ.

θ is used to time-tag experiment data in the experiment computer with an accuracy of 10 s. For this time tagging method, it is assumed that the experiment contains a time counter (counting the 1024 KHz User Time Clock Pulses) which is reset by the User Time Clock update signals every 250ms. For each experiment event, the event data has to be acquired together with the related contents of the experiment time counter. The experiment computer then, by means of θ, calculates back the experiment time counter contents to the onboard time. However, in order to relate the event ambiguously to the onboard time, the data acquisition and computation has to be performed less than 250ms after the event.

θ also allows (together with the User Time Clock, User Time Clock, and GMT) time tagging to be performed autonomously in the experiment. In this case θ compensating GMT signal jitter, can be sent to the experiment via a serial PCM command channel for the correlation between User Time Clock and GMT.

2.3.6. EXPLICITLY TIME TAGGED DATA

GPC downlist parameters which are shipped as a time homogenous set with an associated time tag are called explicitly time tagged parameters. Very few downlist parameters are block protected and explicitly time tagged. Those that are time tagged include Orbiter position, velocity, time and IMU sensed velocity and time. The time at which most parameters were valid must be inferred from their position in the downlink.

The term downlist refers to those GPC parameters placed in the telemetry stream. The downlink consists of all parameters in the telemetry, including the downlist set. Parameters explicitly time tagged will be known to be valid at the time tagged as follows:

Random errors:

o Granularity of GPC software time word	1 μsec
o Granularity of base GPC hardware clock register	1 μsec
o Granularity of MTU 1 sec periodic update	125 μsec
o Other noise and jitter	10 μsec
RSS 3σ error	125.4μsec

2.3.7. NON-EXPLICITLY TIME TAGGED DATA

Time at which non-explicitly time tagged data was valid must be inferred from the positions of the data words in the downlink and a knowledge of the on-board software and telemetry pick-up mechanism. The worst case time tag uncertainty is probably about 2 sec.

3.0 DATA DOWNLINK FORMATS

3.1 GENERALIZED CONCEPTS

This section describes the telemetry data format characteristics anticipated for the early Spacelab flights. In the HRM/HRDM design, two format definitions are used. The engineering format consists of 16 frames with 192 words each. Each frame contains a sync word and a status word. In the status word, the GMT information is transferred with eight bits subcommutated over 16 frames. The frame count is transferred with four bits in the sync word.

The user format consists of eight frames with 96 words. Each frame begins with the sync or the status word of the engineering format. The normal frame is composed of 6 lines x 16 words and is used for all frequencies except 48 MHz, for which the format is arranged in 8 lines x 12 words.

The two definitions are used to identify the contents of the HRM format. The engineering format is the definition of the overall structure, and the user format defines the contents of the format.

Figure 3-1 shows the format strucutre for all binarily related bit rates from 0.125 Mb/s to 32 Mb/s. At 48 Mb/s, the width of both the engineering and user frames is reduced to 12 words and the length is increased to 16 lines for the engineering format and 8 lines for the user format and 8 lines for the user format. The format is output from left to right and top to bottom. Figure 3-2 shows the eight frame user format strucutre for both the 16 column and 12 column cases.

3.2 HRM FORMAT STRUCTURES

The formatting of data within the HRM system is performed according to a set of parameters stored in one of two random access memories (instruction tables). One table is the operating table and the other is free to accept a new set of instructions. The tables are exchanged synchronous to the format after an execution command has been received.

A. <u>Format Programming.</u>

The programmer has to work only with the user format. He has the flexibility to assign each user's share of bandwidth with three types of priority:

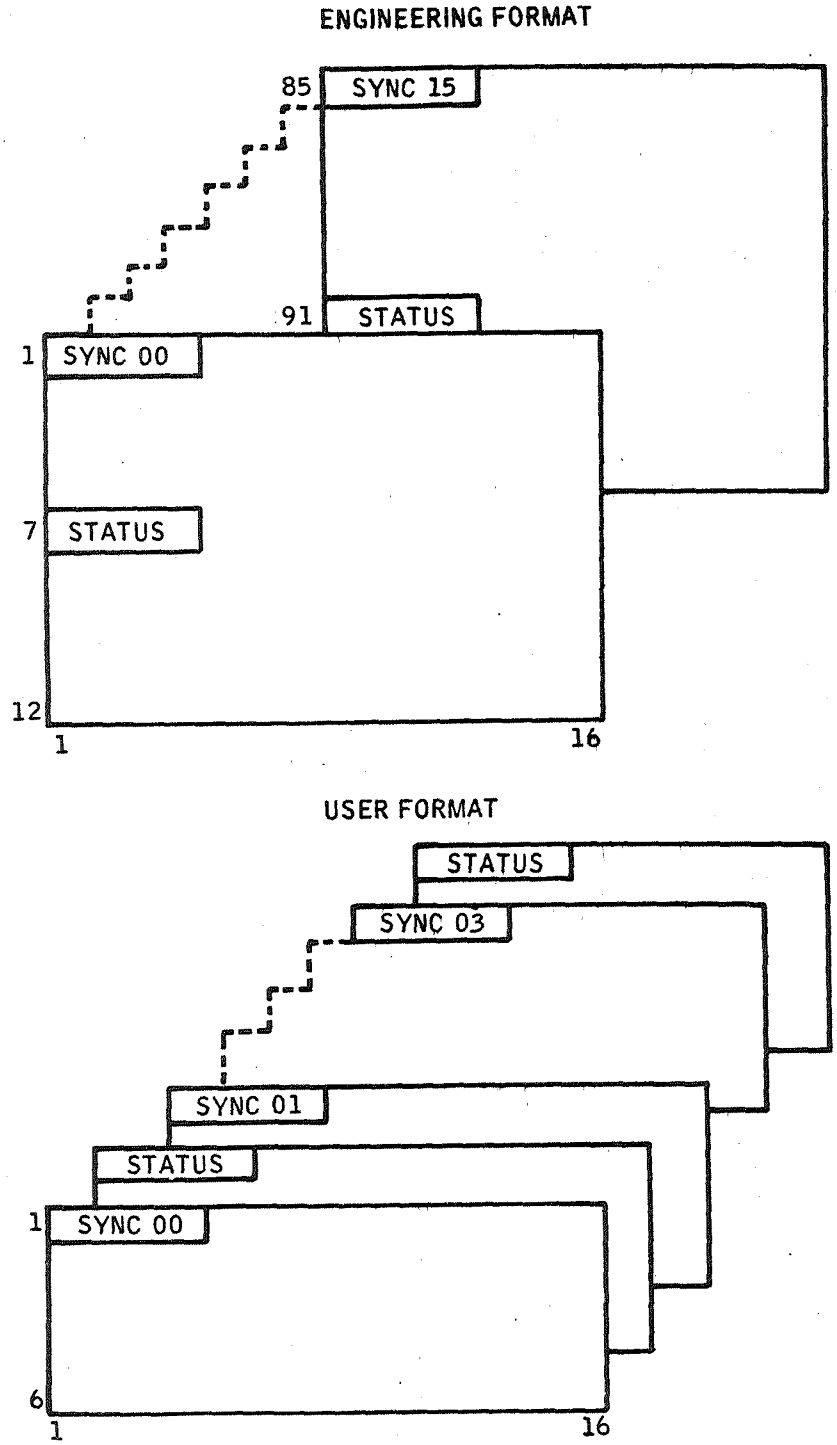


Figure 3-1 Engineering and User Format

FORMAT STRUCTURE 1 IS USED FOR HRM OUTPUT BIT RATES OF 32 MB/S AND ALL LOWER OUTPUT RATES BEING BINARY RATIOS OF 32 MB/S.

FORMAT STRUCTURE 2 IS USED FOR THE 48 MB/S OUTPUT RATE ONLY, SINCE IT IS NOT BINARY RATIO OF 32 MB/S.

THE FRAMES ARE ORGANIZED IN 6 LINES AND 16 COLUMNS IN FORMAT STRUCTURE 1 AND IN 8 LINES AND 12 COLUMNS IN FORMAT STRUCTURE 2. THE LAST WORD IN EACH LINE IS OCCUPIED BY THE FILL WORD IDENTIFICATION. EVEN FRAMES START WITH A SYNC PATTERN, ODD FRAMES WITH A STATUS PATTERN.

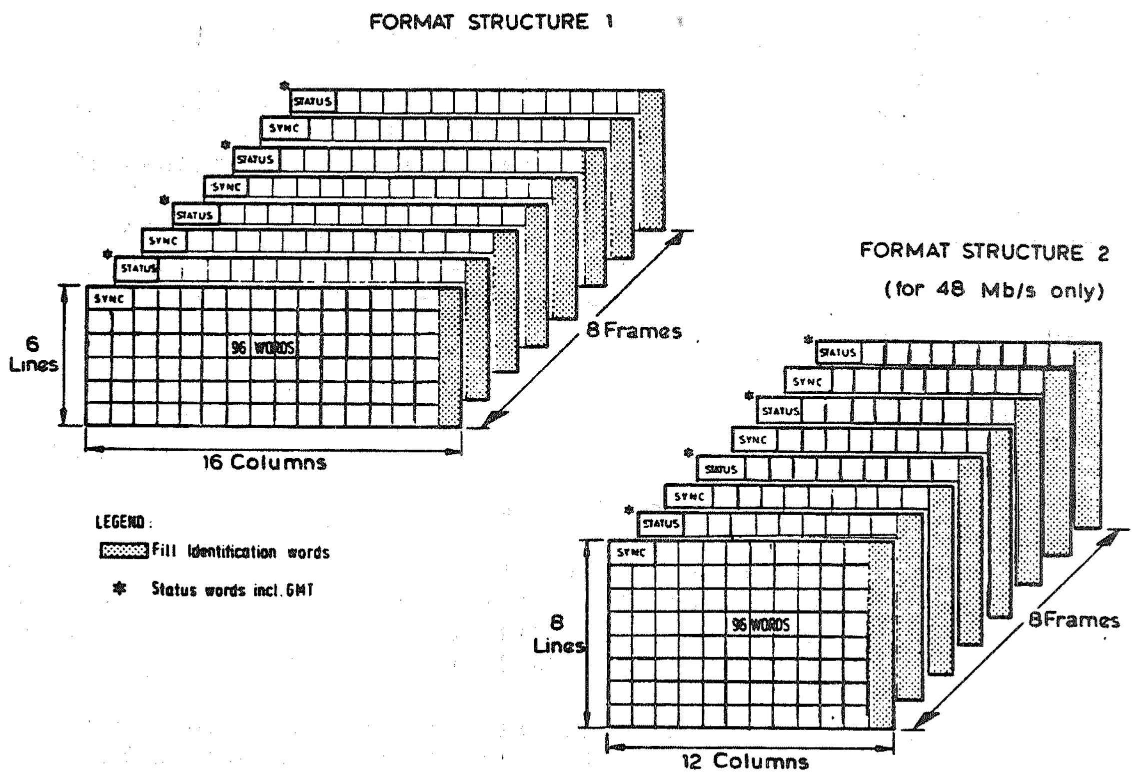


Figure 3-2 HRM Format Structure

- o In mode 3 (highest priority) the number of user words is specified as words per line
- o In mode 2 (lower priority) the number of user words is specified as words per frame and
- o In mode 1 (lowest priority) the number of words is specified as words per format

The formatting of user data is accomplished with a formatting table of 16 consecutive instructions. Each instruction word comprises 16 bits which serve to define two users and their share (number of words alloted to the user):

BITS	DEFINING
0,1	PRIORITY OF INSTRUCTION
2-6	FIRST USER
7,8	NUMBER OF WORDS OF FIRST USER
9,13	SECOND USER
14,15	NUMBER OF WORDS OF SECOND USER

With a set of 16 such instructions, the programmer can assign the bandwidth shares of each user. In addition to the 16 instruction words, the formatting table comprises two configuration status words (words 27 and 38).

B. Constraints.

The HRM-controller offers high flexibility to the programmer, but some constraints are still present.

1. The instruction table must be programmed in a series of descending mode number; that is to say, first entries in the instruction table shall be assigned with Mode 3 instructions followed by Mode 2 and Mode 1 instructions.

2. An odd number of instructions with the same mode has to be increased by a SKIP instruction to give an even number.

3. The number of entries in a table is limited to 32.

4. Special attention should be paid to the last line (No. 18) in the table (instructions 31 and 32). It shall be assigned with mode 1 (end of table) or Mode 1 instruction only. A mode 1 assignment to the last line has the following effects:

   a. If only instruction 31 is used and instruction 32 is a SKIP, the controller will execute instruction 31 until the end of a user format.

b. If both instructions are used, the controller will execute both instructions in an alternating series.

5. The HRM address for I/O Units shall not be 00000, because this code is identical to the clear condition of the input register.

C. Formatting Example.

In figure 3-3 , an example of a particular HRM format is given. Table 3-1 shows the set of instructions defining this format. The nominal data rates allocated to each input channel as a result of this format are given in table 3-2.

D. BITE Format.

The BITE format is the only preprogrammed format in the HRM.

NOTE: Words and lines are numbered from 1 and bits within a word are numbered from 0 (zero).

E. Experiment Bandwidth Selection.

Table 3-3 summarizes the experiment bandwidths made available by selecting appropriate format parameters.

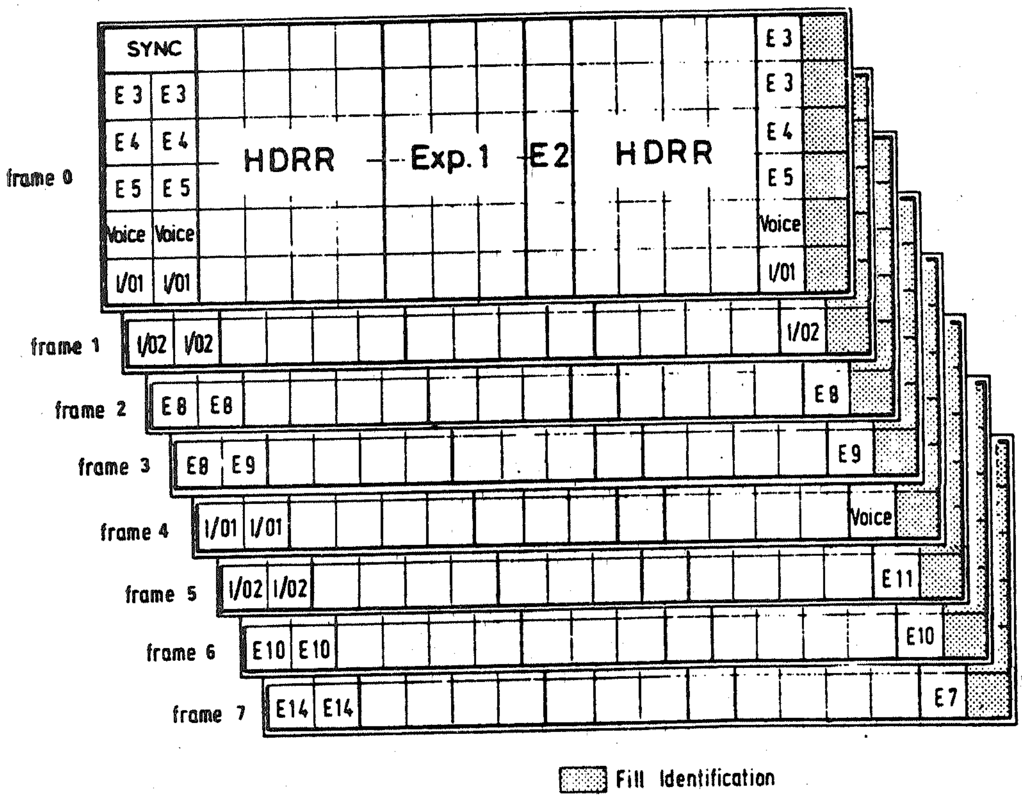


Figure 3-3 Example of HRM Format

TABLE 3-1

EXAMPLE OF INSTRUCTION TABLE

Instruction Word	Mode	Channel	Words	Channel	Words
1	3	HDRR	4	E 1	3
2	3	E 2	1	HDRR	4
3	2	E 3	4	E 4	3
4	2	E 5	3	Voice	3
5	1	I/01	3	I/02	3
6	1	E 8	4	E 9	2
7	1	I/01	2	Voice	1
8	1	I/02	2	E 11	1
9	1	E 10	3	E 14	2
10	1	E 7	1	Skip	0
11	0	Skip	0	Skip	0
12	0	Skip	0	Skip	0
13	0	Skip	0	Skip	0
14	0	Skip	0	Skip	0
15	0	Skip	0	Skip	0
16	0	Skip	0	Skip	0
17	Configuration Status				
18					

TABLE 3-2

EXAMPLE OF RATE SHARING

HRM Output Data Rate = 4 Mb/s	
Data Rate Shares	Data Rate Shares
E 1 ≤ 750 kb/s	E 11 ≤ 5.2 kb/s
E 2 ≤ 250 kb/s	E 12 = -
E 3 ≤ 166.6 kb/s	E 13 = -
E 4 ≤ 125 kb/s	E 14 ≤ 10.4 kb/s
E 5 ≤ 125 kb/s	E 15 = -
E 6 = -	E 16 = -
E 7 ≤ 5.2 kb/s	I/O 1 ≤ 26 kb/s
E 8 ≤ 20.8 kb/s	I/O 2 ≤ 26 kb/s
E 9 ≤ 10.4 kb/s	HDRR ≤ 2000 kb/s
E 10 ≤ 15.6 kb/s	PLR = -
	Voice ≤ 130.2 kb/s

(HRM Voice fixed at 128 kb/s)

TABLE 3-3

EXPERIMENT BANDWIDTHS

PARAMETER	OUTPUT BIT RATE 48	32	16	8	4	2	1	0.5	0.25	0.125
WORDS/ LINES	MB/S	MB/S	MB/S	MB/S	MB/S	KB/S	KB/S	KB/S	KB/S	KB/S
4	16	8	4	2	1	500	250	125	62.5	31.25
3	12	6	3	1.5	0.75	375	187.5	93.75	46.88	23.44
2	8	4	2	1	0.5	250	125	62.5	31.25	15.63
1	4	2	1	0.5	0.25	125	62.5	31.25	15.63	7.81
WORDS/ FRAME	MB/S	MB/S	KB/S	KB/S	KB/S	KB/S	KB/S	KB/S	KB/S	KB/S
4	2	1.333	666.7	333.0	166.7	33.33	41.67	20.83	10.42	5.21
3	1.5	1	500	250	125	62.5	31.25	15.63	7.81	2.60
2	1	0.667	333.3	166.7	83.33	41.67	20.83	10.42	5.21	1.30
1	0.5	0.333	166.7	83.33	41.67	20.83	10.42	5.21	2.60	0.65
WORDS/ FORMAT	KB/S	KB/S	KB/S	KB/S	KB/S	KB/S	KB/S	KB/S	B/S	B/S
4	250	166.7	83.33	41.67	20.83	10.42	5.21	2.60	1302	651
3	187.5	125	62.5	31.25	15.03	7.81	3.91	1.95	977	488
2	125	83.33	41.67	20.83	10.42	5.21	2.60	1.30	651	326
1	62.5	41.67	20.83	10.42	5.21	2.60	1.30	0.651	326	163

3.3 HRDM FORMAT STRUCTURE

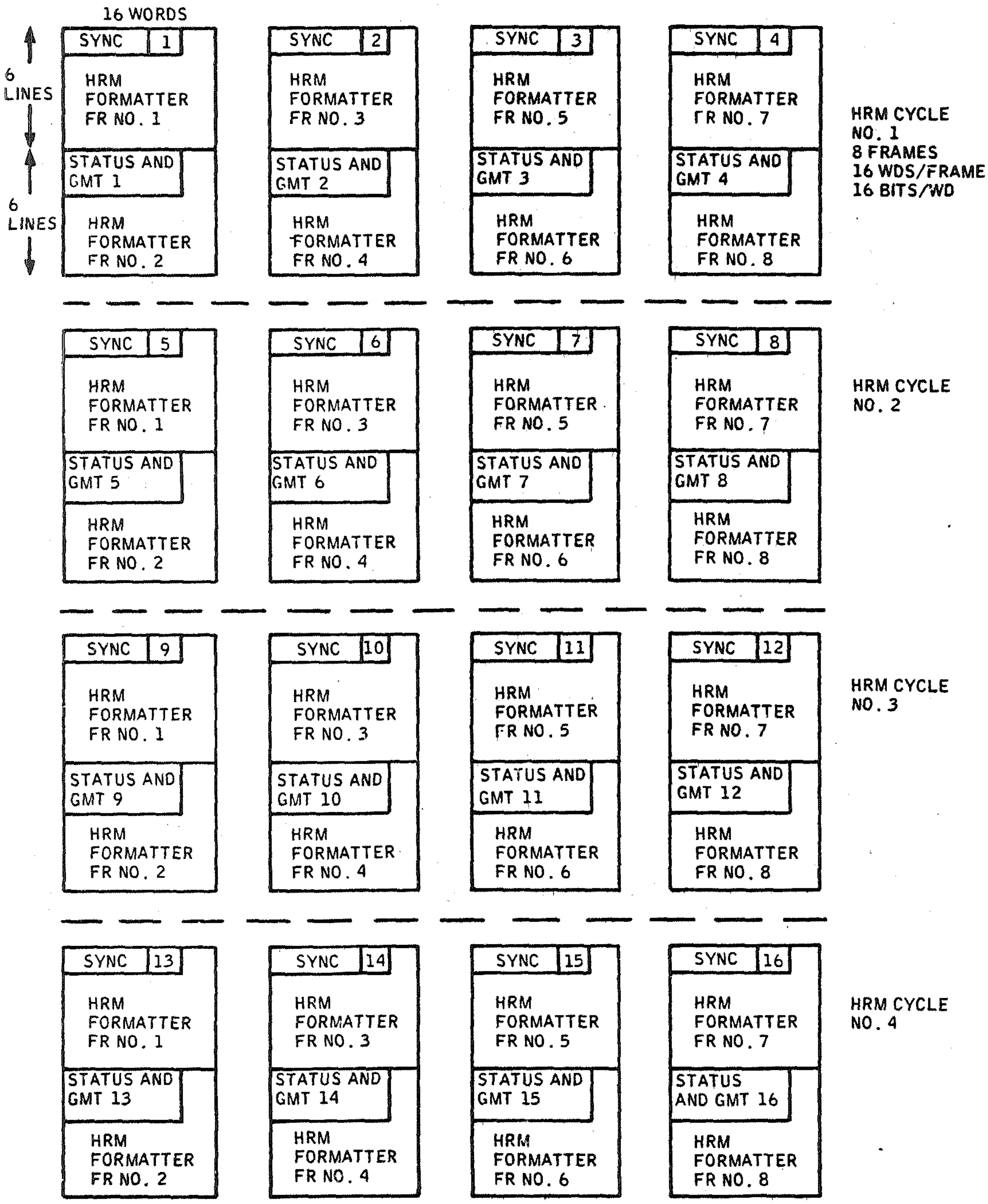
The HRDM format generator stores up to 16 user formats in 16 programmable read-only memories (PROM's), plus two formats in read/write (R/W)memories. The 16 formats in the PROM's are installed prior to a mission according to the formats in the R/W memories can be user programmed and selected by the ground computer terminal. The HRDM operation is oriented to the 16-frame engineering format with each frame containing 192 words. Figure 3-4 illustrates the relationship of the engineering format to the 8-frame user format around which the HRM formatting is structured. The key points of the overall structure are as follows:

A. The HRM formatter operates on an 8-frame, 96-word/frame basis; therefore, the basic HRM format is repeated four times within the engineering format.

B. Although the HRM formatter is oriented to 8-frames, there is a frame counter in the HRM which counts frames 0-15 (4-bit counter). This count identifies the engineering frame and is included as part of the pattern for synchronizing the HRDM.

C. The frame count is also used to identify the data contained in the GMT portion of the status words. The GMT is subcommutated across 16 engineering frames, 8-bits at a time.

The basic demultiplexing scheme of the HRDM is to use the word counter address to interrogate a table which contains 768 words. These words specify a device number for each one of the 768 words in the engineering format. The device number is the HRDM nomenclature for output channels. These numbers correspond to HRM experiment and recorder inputs.



NOTE: SINCE HRM CYCLE IS REPEATED 4 TIMES, THE HRDM FORMAT TABLES CONSIST OF 768 ENTRIES (8 HRM FRAMES X 96 WORDS)

Figure 3-4 HRDM FORMAT (16 FRAMES, 192 WORDS/FRAME, 16 BITS/WORD)

3.4 GMT

The GMT and flight number data which is subcommutated across the 16 frames of the engineering format will be output in a serial burst of 56 bits once each engineering format. The format of the HRDM output will be as shown below.

	BIT No.
o Flight No. (0-99):	0 - 7
o Year + Day (x 100) (0-9/0-9):	8 - 15
o Days (0-99):	16 - 23
o Hours (0-23):	24 - 31
o Minutes (0-56):	32 - 39
o Seconds (0-59):	40 - 47
o Seconds (÷ 100) (0-99)	48 - 55

The data is BCD coded inside the pattern. Synchronously with the beginning of each engineering format, the GMT pattern will be serially output (bit zero first) from the HRDM in a burst of 56 bits. The GMT output bit rate shall be equal to the HRDM input bit rate divided by 512. The seconds (÷ 100) shall be decommutated from the first frame of a format.

If Spacelab data is downlinked in a packet form, i.e., a block of data coming from one experiment or instrument which has been accumulated in a buffer within the experiment system and held until appropriate time for transmission, the Spacelab GMT time tag denotes the time the packet assembly was begun. To facilitate time correlation of the data, the acquisition of data samples for the packet should be accomplished according to a regular schedule which will give each data point a known relationship with the time tag, or information should be included in the data format within the packet to allow correlation to the time tag.

Section 4

Additional Findings

4.1 DATA STALENESS

A formulation has been developed for determining the delta time to be subtracted from the GPC downlist header time to correct for the time interval between the actual read of an input signal and its insertion into the downlist buffer (See reference 2 for further information). This residual staleness can be as high as 160 milliseconds for raw measurements that the GPC acquires either in the High Frequency Executive or the Mid-Frequency Executive read.

4.2 EQUIPMENT REDUNDANCY

Several key elements of the Spacelab timing distribution system are not redundant and loss of any unit would result in a significant loss of science data.

- HRM - Loss of all science data.
- RAU - Loss of ability to interact with experiments. Could result in significant loss of science data since several experiments interface with a RAU.
- RAAB - Loss of timing signal to CDMS computers and HRM. However, the computers can continue to distribute timing internally (accuracy unknown). No Additional redundancy in the timing system is being requested at this time.

4.3 NAVAGATION PARAMETERS

State vector components are time homogenous and the time tags are available to users in the telemetry downlist formats.

4.4 RAU DATA ACQUISITION AND CONTROL SOFTWARE

Software for RAU data acquisition and control must be provided by the user.

4.5 TIME TAGGED INFORMATION AVAILABLE TO PAYLOAD

Postiion, velocity, and time are sent over at a 0.52 hz rate in earth fixed coordinates. The use of earth fixed coordinates is desirable because the UTC time tag is slightly more valid for earth fixed vectors than for inertial (Mean 1950) position and velocity vectors because of approximations in the transformation from inertial to earth fixed coordinates via UTC/UT1. Attitude and trim are sent over at a 0.52 hz rate as roll, pitch, and yaw angles in earth fixed body coordinates.

The above data, when received at the Payload will be stale be about 60 μsec nominally (80-100 μsec worst case). This staleness is due to General Purpose Computer Software cycling and internal buffering.

APPENDIX A

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APPENDIX B

TIME SCALES

B.1 INTRODUCTION

A system of assigning dates to events is called a time scale. This appendix will briefly discuss several time scales, beginning with apparent Solar Time and ending with Coordinated Universal Time. This appendix is not meant to be an in depth discussion of time scales. The intent of this appendix is to give a simplified definition of Coordinated Universal Time (UTC). This can be done best by presenting a chronoligical development of time scales.

B.2 APPARENT SOLAR TIME

Time derived from the apparent position of the sun in the sky is called "apparent solar time". An apparent solar day is dependent upon the motion and orientation of the earth and the position of the sun. Measurements made with a sun dial, for example, give apparent time since it is in terms of the actual relative position of the sun. If the earth's orbit were a perfect circle and lay in the plane of the earth's equator with uniform rotation, the length of an apparent solar day would be fairly constant throughout the year. The earth's orbit, however, is ecliptical and is inclined to the earth's equator at an angle of approximately 23.5°. Also, the orbital speed of an object traveling in an eclipse is not constant. As a result apparent days vary in length. Mean Solar Time is simply Apparent Solar Time averaged to eliminate orbital variations. The difference between Apparent Solar Time and Mean Solar Time is called the equation-of-time. It has a maximum value early in November when the difference is about 16 minutes.

B.3 MEAN SOLAR TIME

As mentioned above, Mean Solar Time is simply apparent time averaged to eliminate variations due to the earth's orbital eccentricity and the inclination earth's axis of rotation to it's orbit. A Mean Solar Day is the average of all the apparent solar days throughout the year and the mean solar second is equal to a mean solar day divided by 86,400. As a fundamental unit of time, the mean solar second is inadequate because it is still tied to the rotation of the earth which is now known to be non-uniform.

A solar year is a measure of the period of the earth's revolution around the sun. A solar year is presently equal, in Mean Solar Time, to 365 days, 5 hours, 48 minutes and 45.5 seconds (365.2422 Mean Solar Days). Since the solar year by which we record time is not an integral multiple of mean solar days, corrections must be made to our calendar at times to make the data correspond to the position of the sun.

B.4 UNIVERSAL TIME

If one considers a distant star instead of the sun to measure the length of the day, the effect of the earth's ecliptical orbit becomes unimportant and can be neglected. Universal Time is based solely upon the rotation of the earth about it's axis. The units of Universal Time (UT) were chosen so that, on the average, local noon would occur when the sun was on the local meridian. UT, thus defined, made the assumption that the rotation of the earth was constant. It is now known that the earth's rotation is subject to periodic and irregular variations. When uncorrected, the units of UT are equivalent to the mean solar second, and are identified as a time scale by the designation UT^0. UT^0 is the mean solar time, the Greenwich Meridian, sometimes called Greenwich Mean Time (GMT). Correction to UT^0 has led to two subsequent Universal Time Scales: UT^1 and UT^2.

The development of better clocks revealed a discrepancy in UT^0 measured at different locations. The cause of this was traced to the fact that the earth wobbles on it's axis as it rotates. The location of the pole of the earth wonders over a range of 15 meters during a period of several years. By comparing astronomical measurements made at various locations throughout the world, one can correct for this effect and obtain a more uniform time scale -denoted UT^1. UT^1 is based solely on the true angular rotation of the earth.

With the development of quartz crystal clocks, it was discovered that UT^1 had fluctuations with periods of one-half and one year. These variations are apparently caused by seasonal changes in the distribution of matter over the earth's surface, e.g., changes in the amount of ice in the polar regions as the sun moves from the sourthern hemisphere to the northern hemisphere and back again throughout the year. This cyclic redistribution of mass effects the earth's rotation since it amounts to seasonal changes in its moment of inertia. The natural response was to remove these fluctuations and obtain an even more uniform time. This time scale was called UT^2.

B.5 INTERNATIONAL ATOMIC TIME

The International Second was formally adopted in October, 1967, by the XIII General Conference of Weights and Measures. The General Conference defined the second as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium atom 133.

The atomic definition realizes an accuracy much greater than that acheived by astronomical observations. It results in a time base more uniform and convenient. Determinations can now be made in a few minutes to a greater accuracy than was possible before in measurements that took many years.

International Atomic Time (TAI) therefore is the accumulation of atomic seconds from a particular date, 1 January, 1958, when TAI was approximately in coincidence to UT^2. On that day, the epoch of Atomic Time was made 0h, 0m, 0S when UT^2 was 0h, 0m, 0S.

B.6 COORDINATED UNIVERSAL TIME (UTC)

Prior to 1 January, 1972, to approximate UT in laboratories, the frequency of a precision oscillator such as a cesium or rubidium clock was offset from its nominal frequency by an amount that allowed the clock rate to be nearly coincident with UT^2. Small differences were corrected periodically (called step-time adjustments) to maintain synchronization with UT^2. The changes in offsets and step-time adjustments were accomplished simultaneously throughout the world, through the announcements made by the "Bureau International de l'Heure" (BIH). This method of timekeeping is identified as Coordinated Universal Time (UTC).

On 1 January, 1972, the UTC system was improved to allow UTC time to accumulate at the same rate as International Atomic Time, and thereby eliminate the problems of operating systems with frequency offsets. At the same time, the step-time adjustments were changed from .1 to 1-second.

The step-time adjustments are now called "leap seconds". The leap seconds are introduced into UTC time to keep synchronization with UT[1] to within ±0.7seconds(this may be raised to ±0.95 seconds). These adjustments, when required, should be the last day of a UTC month, preferably 31 December and/or 30 June. Table B-1 provides a history of offsets and step-time adjustments in UTC since 1 January, 1961.

TABLE B.1
OFFSETS AND STEP ADJUSTMENTS OF UTC

DATE (0 h UT)		FREQUENCY OFFSET $(\times 10^{-10})$	STEPS (SECONDS) UTC (new) - UTC (old)
1961	Jan 1	-150	
	Aug 1	-150	+0.050
1962	Jan 1	-130	
1963	Jan 1	-130	-0.100
1964	Jan 1	-150	
	Apr 1	-150	-0.100
	Sep 1	-150	-0.100
1965	Jan 1	-150	-0.100
	Mar 1	-150	-0.100
	Jul 1	-150	-0.100
	Sep 1	-150	-0.100
1966	Jan 1	-300	
1968	Feb 1	-300	+0.100
1972	Jan 1	0	-0.1077580
	Jul 1	0	-1.0
1973	Jan 1	0	-1.0
1974	Jan 1	0	-1.0

APPENDIX C

TIME COUPLER

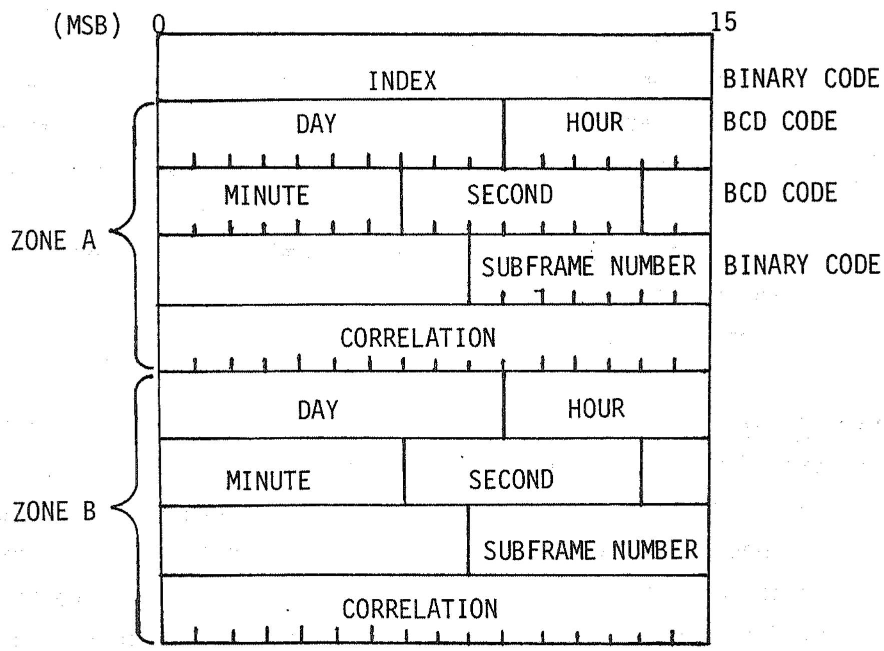
C.1 INTRODUCTION

The Time Coupler performs two basic functions relating to the time tagging of Spacelab data. These functions are: decoding and storing in the Experiment Computer memory GMT and information correlating GMT to the User's Time Clock;and providing to experimenters, through the RAU's, a time reference correlated to the GMT. This time reference is a 1024 KHZ clock in which a marker is added every 250ms. The Time Coupler and its associated interface is not redundant.

C.2 TIME COUPLER FUNCTIONS

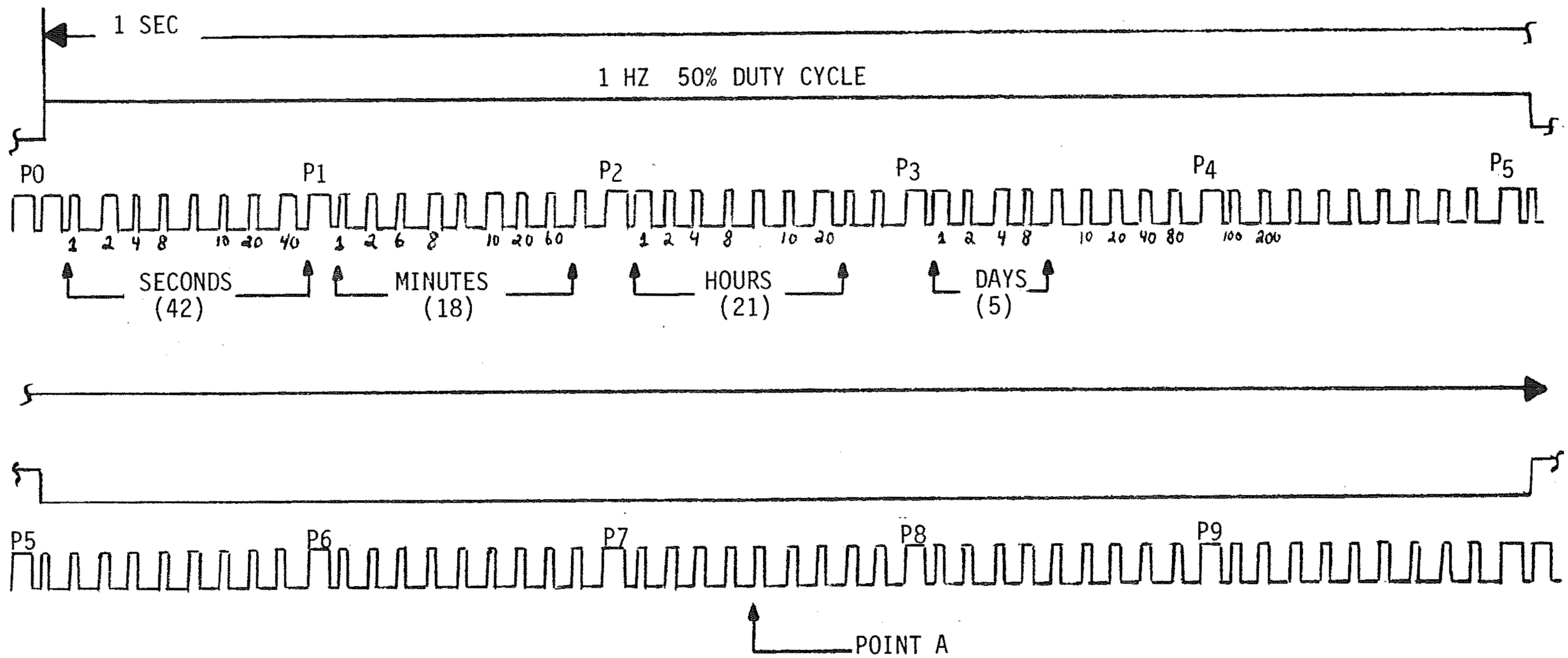
The different functions of the Time Coupler will be described in detail in this section. The information supplied to the Experiment Computer occupies nine words of core: one index word puts two zones of four words each. The format of the stored data is shown in Figure C-1. The value of the index determines if the data is to be stored in Zone A or in Zone B. The value of the index is modified every 250ms.

C.2.1 GMT Decoding. The Time Coupler receives IRIG-B coded GMT from the Orbiter through the Remote Acquisition Advisory Box (RAAB). A frame of the GMT received is shown schematically in Figure C-2. The frame time is one second and is made up of 100 elementary pulses which are modulated in width. The day, hour, minute, and second are in a Binary Coded Decimal (BCD) format. The identification of the pulse is given by its width: 8ms for a position identifier, 5ms for a binary 1, and 2ms for a binary 0. The accuracy of a pulse width is $\pm$ 50μs. The "on time" reference of the frame is the leading edge of the position identifier which follows Po. The 10ms resolution is obtained by counting the elementary pulses and adding this time to the "on time" that is coded into the pulse. For example, the time at point A in Figure C-2 is five days, twenty-one hours, eighteen minutes, and 42.75 seconds.



EXPERIMENT COMPUTER TIME WORD FORMAT

Figure C-1



- o 100 PPS (10ms between pulses)
- o BCD
- o Position Identifier - 8ms duration
- o Binary 0 - 2ms duration
- o Binary 1 - 5ms duration
- o Time at Point A
  5 days, 21 hours, 18 minutes, 42.75 seconds

GMT CODED INTO IRIG-B FORMAT

Figure C-2

C.2.1 <u>GMT Decoding</u> (Cont'd).

The decoding criteria for the IRIG-B GMT can be defined in terms of pulse width detection a time gap (called Δt) separating a fall time to a rise time of two successive GMT pulses is interpreted as follows:

$$\Delta t < 3.5\text{ms} = \text{marker}$$
$$3.5 < \Delta t < 6.5\text{ms} = \text{logical } 1$$
$$6.5 < \Delta t < 9\text{ms} = \text{logical } 0$$

A one second frame of GMT is composed of 100 elementary pulses. Each frame is started by a double marker called P0. This double marker is detected by the coupler for synchronization purposes (see Figure C-2). The other markers, P1 through P9, encountered in a one second frame are used to increment the subframe counter.

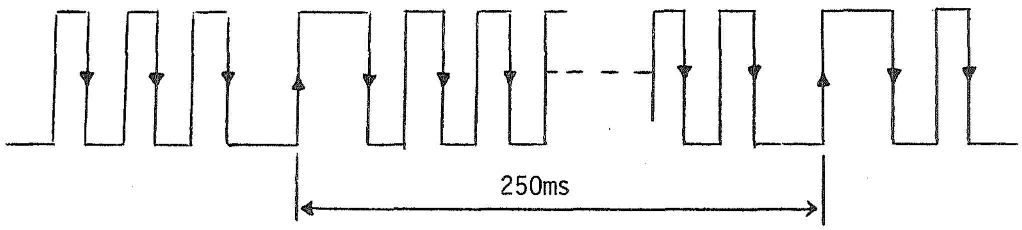
The GMT received by the coupler is subject to certain validity conditions. The GMT is considered valid when the coupler has detected one complete frame. The maximum lockup time for this is two seconds. The GMT is not considered valid if the pulse width is not in accordance with the detection criteria or if no pulse is present for a time period greater than 10ms.

Once the GMT has been decoded it is stored into the first two time registers as shown in Figure C-1. These two registers are updated every second. There is also a third time word which gives the subframe number inside a period of one second. This number is stored in binary form in the third time register and is updated every 10ms. As a result, the GMT available to the experiments has a resolution of 10ms.

C.2.2 <u>Time Tagging</u>. The 1024 KHZ signal generated by the MTU is routed through the RAAB to the Time Coupler in the experiment I/O Unit. The Time Coupler generates a composite clock. This composite clock is the 1024 KHZ in which a marker has been added every 250ms. This marker is obtained by a phase modulation of the 1024 KHZ clock with a modulation depth

C.2.2 Time Tagging (Cont'd).

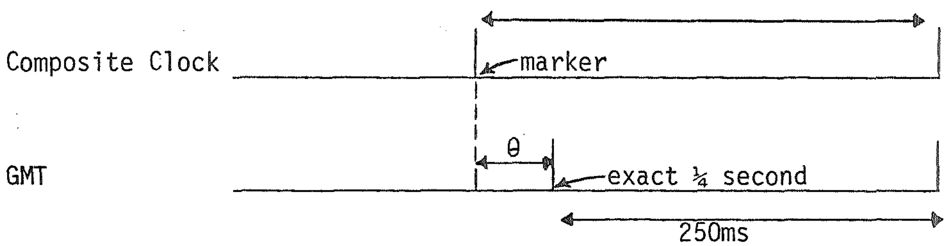
of 180 degrees in one clock period. That is, the composite clock has not only the same frequency, duty cycle, and drift of the 1024 KHZ clock signal, but in addition, a correlated sync pulse starting negative transition and followed by a positive transition that has double the period of the 1024 KHZ clock every 250ms. The composite clock obtained from the modulated 1024 KHZ clock is shown in Figure C-3.



COMPOSITE CLOCK DERIVED FROM 1024 KHZ

Figure C-3

The Time Coupler provides to the Experiment Computer the phase relationship between the marker and the exact ¼ second of GMT. This information is called correlation (θ) , its origin being the beginning of the marker (see Figure C-4). The uncertainty in the correlation information is 4μs (see Section 2.3.5). In order to take



PHASE DIFFERENCE BETWEEN GMT AND COMPOSITE CLOCK

Figure C-4

C.2.2 Time Tagging (Cont'd).

into account the time delay of the composite clock inside the RAU $8\mu s$ is subtracted from the phase measurement, σ, in order to obtain the correlation information, i.e. $C = \sigma - 8\mu s$. This information is then stored into the Experiment Computer time buffers, as shown in Figure C-1, and can be used for experiment time tagging (see Section 2.3.5).

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